Urban Impact Assessment and Emergency Response to Flooding in Buenos Aires, Argentina

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Abstract

The determination of urban resilience and community response to flooding are significant aspects of hazard management and disaster risk reduction. Anticipating hazard impacts is vital to the development of flood mitigation strategies and emergency response planning. Argentina is an emerging economy with high flood hazard exposure, and its capital, Buenos Aires, is one of the most affected areas. Inappropriate disaster response could therefore affect food supply chains, telecommunications and transport systems nationwide. Flood risk areas in Buenos Aires City have been geographically identified. However, flood impacts have not been well considered, and the emergency response capacity of the city has not been evaluated. This research examined flood impacts in Buenos Aires on infrastructure lifelines and critical facilities, as well as on the wider commercial and residential built environment under current conditions, and accounting for projected impacts of climate change. Evacuation dynamics were explored through characterising spatiotemporal population exposure, modelling evacuation routes, and analysing emergency service response areas. Analyses of different sea-level rise and storm return interval scenarios showed clear trends in increasing impacts under increasing hazard intensities; these impacts were ameliorated when flood warnings were applied. Spatiotemporal population exposures developed for evacuation analyses showed increasing impacts under increasing sea-level rise scenarios. Dynamic evacuation analyses highlighted inadequacies in current welfare facilities to shelter evacuees, however modelling suggests that shelter and emergency response can both be improved by increasing the number of facilities. This research contributes to the quantification of impacts on the built environment and associated economic losses, and helps inform disaster response and management. The methodological approach presented here provides an analytical framework for flood impact analyses and evacuation dynamics that can inform other flood-exposed cities globally.

Acknowledgements

I wish to express my gratitude to my supervisors, Dr. Matthew Hughes and Dr. Tom Cochrane, for their support, encouragement and the freedom they offered me to do research in Buenos Aires (BA), my home city, and to try new things in the geographic information system (GIS) field. I am happy to say that I became a competent GIS user because of their guidance and tutoring time. I also want to highlight their support of my attendance at conferences and courses, in particular for letting me attend their risk management class, which allowed me to gain a better understanding of the topic and to realise how useful GIS can be for risk management. Also, Dr. Tom Cochrane invited me to be his GIS assistant in one of his courses to further improve my skills.

I wish to thank New Zealand Aid for my master's degree scholarship. I could not have chosen a better place to study water resource and hazard management. I also wish to acknowledge the Waterways Centre, the University of Canterbury (UC) Student Care and the Civil and Natural Resources Engineering Department for dealing with administrative issues.

I wish to thank my friends and flatmates in New Zealand, who gave me their feedback on my rehearsal presentations and made my master’s programme more enjoyable. My family and friends in Argentina always encouraged me to pursue a master's degree, even though that meant being away from home, and their long-distance support when I was feeling a bit homesick proved invaluable.

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Chapter 1

Defining Flood Hazards

Context of Study

The Intergovernmental Panel on Climate Change (IPCC) has analysed the causes and consequences of climate change and sea level rise (Church et al., 2013), and adaptation measures for urban environments (Revi et al., 2014) have been published in accordance with IPCC projections. In addition, the *Sendai Framework for Disaster Risk Reduction 2015–2030* (United Nations Office for Disaster Risk Reduction [UNISDR], 2015) has established targets, such as a substantial reduction in the number of affected people, economic losses and damage to critical infrastructure caused by disasters, both natural and manmade, including climate change, sea level rises and floods (UNISDR, 2015).

Given the relevance of IPCC projections and the Sendai Framework to Argentina, the Argentinian government and scholars have devoted efforts to better understand and manage risk. Argentina is among ten emerging economies with the highest flood hazard exposure (World Bank, 2016), and its capital, Buenos Aires (BA), is one of the most affected areas. The city provides a good example of a developing city highly vulnerable to floods. Between 1984 and 2004, the city suffered 37 flood events (World Bank, 2005), equating to more than one event per year and millions of dollars in damage, as in 2013, when the city suffered a USD 300 million loss (World Bank, 2016). Changes in wind direction, more frequent storm events and sea level rises have led to flood risks becoming more significant (Lecertua, 2010).

Given that BA is the national capital, an inappropriate disaster response and recovery effort could have far-reaching consequences on food supply chains, telecommunications, and the national and international transport system. Because it is the main business, financial, cultural and political centre of Argentina, the city contributes 24% of the nation's gross domestic product (World Bank, 2016).

The fact that a large coastal area of the BA's La Plata River is within 5 m of mean sea level (Re & Menéndez, 2005) (Figure 1) and the city is the largest populated area in the country, with approximately 3 million inhabitants (Argentina's National Institute of Statistics and Censuses [INDEC], 2010), many people can be affected by floods. Flood impacts affect not only city inhabitants, but also 2 million daily commuters from suburban areas and other provinces who enter the city to study, work or make use of health or entertainment facilities (World Bank, 2016).

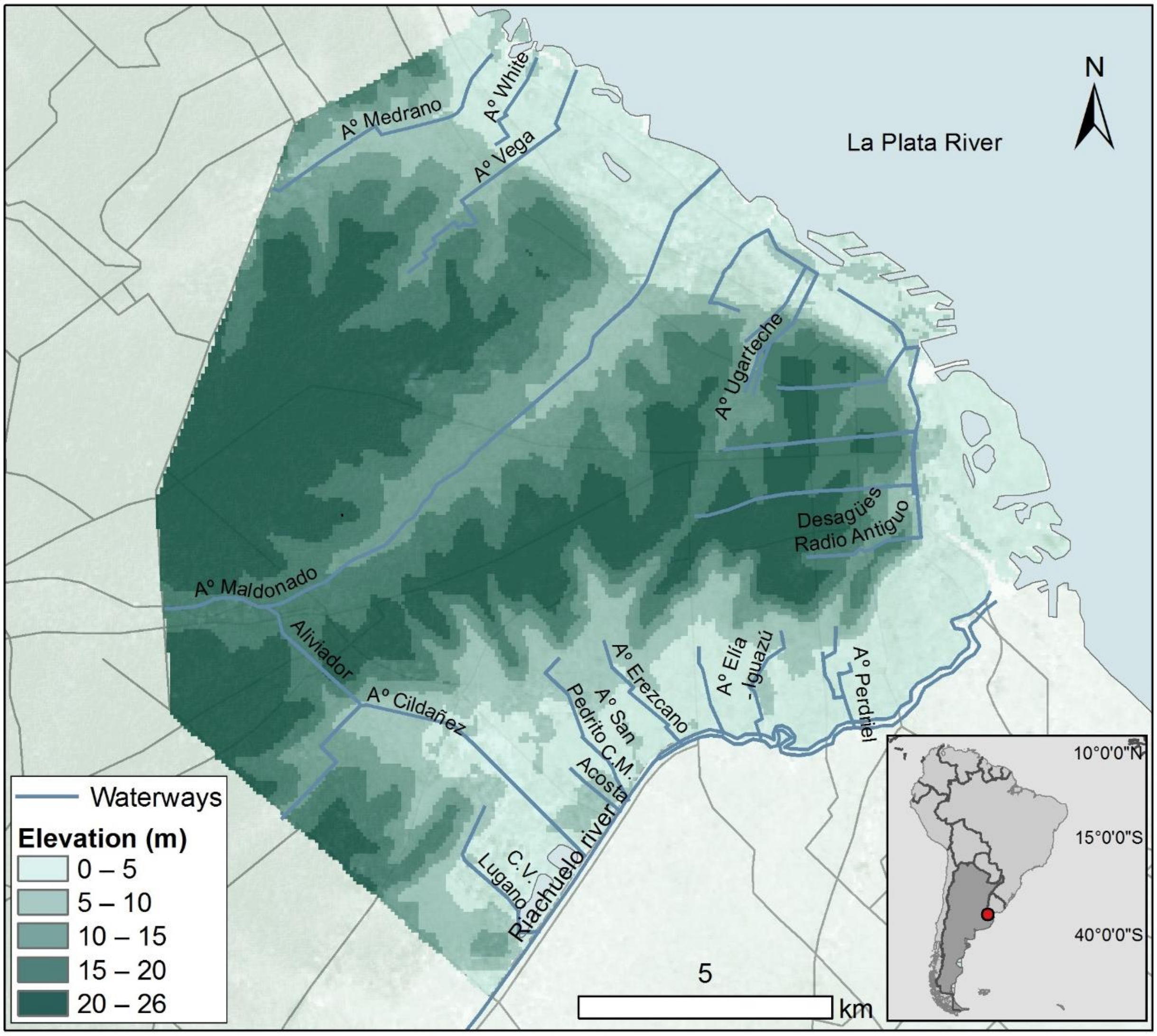

Figure 1. Buenos Aires elevation map and waterways.

Note. Map created by the author with raw data obtained from https://data.buenosaires.gob.ar/dataset (GCABA, n.d.).

It is also important to take into account that the effects of flood events go beyond their immediate impact. For instance, power outages can last from a couple of hours up to several days, as experienced in April 2013, when several neighbourhoods were without power for 15 hours or more (World Bank, 2016). In BA, subsidies or tax exemptions are offered to the victims of flood events, which cause a negative impact on the city budget. The flood events that took place in April 2012 and April 2013 resulted in a USD 49 million budget impact on the city (World Bank, 2016). Furthermore, clean-up, restoration and reconstruction processes can also take a long period, depending on the resilience levels of each family, and the regional economic context.

Flood causes are well understood by the city authorities and scholars (Lecertua, 2010; World Bank, 2016). Flood risk areas in BA have already been geographically delineated (Lecertua, 2010; Re & Menéndez, 2005) by modelling software. They have also been investigated from socioeconomic (Costa, 1988; Natenzon et al., 2003) and political (González, 2005) perspectives by analysing average income levels and the government's flood management strategies in risk areas. However, the relationships between flood risk, vulnerability, potential damage and the city's response capacity have not yet been deeply analysed. The potential damage to buildings and their contents has not been quantified as a function of their use (residential, commercial or industrial), which will be done in this research. Furthermore, no evacuation models or assessments of emergency facilities' service areas have been developed yet. Therefore, evacuation scenarios and service areas will be evaluated in order to increase the knowledge in this field and potentially improve flood risk management and response capacity in BA.

Literature Review

The *Sendai Framework for Disaster Risk Reduction 2015–2030* (UNISDR, 2015) set up an outline to better understand disaster risk, and to enhance risk management. In particular, risk can be assessed in terms of hazard, exposure and vulnerability (Figure 2). Hazard is understood as a process, phenomenon or activity capable of causing damage. Exposure comprises the persons and assets that can be affected by hazards, while vulnerability is determined by the factors or processes that influence susceptibility to the impacts of hazards (UNISDR, 2017). These three concepts define risk in terms of potential losses (deaths, injuries and damage to property) in a system or society. In this thesis, all these concepts are used to structure the literature review of flood risk.

Figure 2. Disaster risk terminology. Risk can be assessed in terms of hazard, exposure and vulnerability (United Nations Platform for Space-based Information for Disaster Management and Emergency Response [UN-SPIDER], n.d).

Floods in Buenos Aires

Floods in BA have two main natural causes: high-intensity rainfall and high tides affecting the La Plata River, usually exacerbated by strong southerly winds (known as "Sudestadas"), which make drainage of the river into the sea more difficult. Southerly winds occur all year round, but they are more frequent in summer (Escobar et al., 2004). Furthermore, the low gradient of the BA plains as they slope towards the La Plata River does not facilitate water drainage (Clichevsky & Herzer, 2000).

Climate variability has worsened the issue in several ways. For example, Escobar et al. (2003) found that the South Atlantic anticyclone has increased its intensity and has altered its route towards the south since the 1970s, especially during summer. Consequently, the intensity of the winds that go through the La Plata River estuary has also increased and shifted towards the east. In addition, Castañeda & Barros (1994) reported that average annual rainfall has increased since the 1950s. The frequency of high-intensity rainfall has increased as well (Lecertua, 2010). These variations partially explain the rise in the median water level of the La Plata River, which has been approximately 17 cm in the 20th Century (D'Onofrio et al., 2003).

The El Niño–Southern Oscillation (ENSO), a global climate cycle that disrupts regular patterns of wind and rainfall, influences the behaviour of the La Plata River. However, no big changes have been observed in monthly mean hourly water levels (0.10 m), or in monthly maximum high waters recorded in BA (D'Onofrio, Fiore, & Romero, 1999). In this regard, it is important to consider that climate change can alter the behaviour of the ENSO, and that its intensity has increased during the last three decades (UN, 2009). Climate change also contributes to sea level rises (IPCC, 2013), and increases in temperature and precipitation, as reported in the Third National Communication on Climate Change (Sea and Atmospheric Research Centre [CIMA], 2016), and as plotted on climate change risk maps for Argentina (The Ministry of Environment and Sustainable Development, Argentina [MAyDS], n.d.).

In addition to these processes, anthropogenic factors affect flood risk (Figure 3). For instance, the shift of drinking water sources from groundwater to the La Plata River, and reduced groundwater taken during economic recessions, have caused a rise in groundwater levels. The rise in groundwater levels has triggered occasional inundation of basements and underground garages, failure of sanitation systems and sewage overflows (Foster & Garduño, 2002).

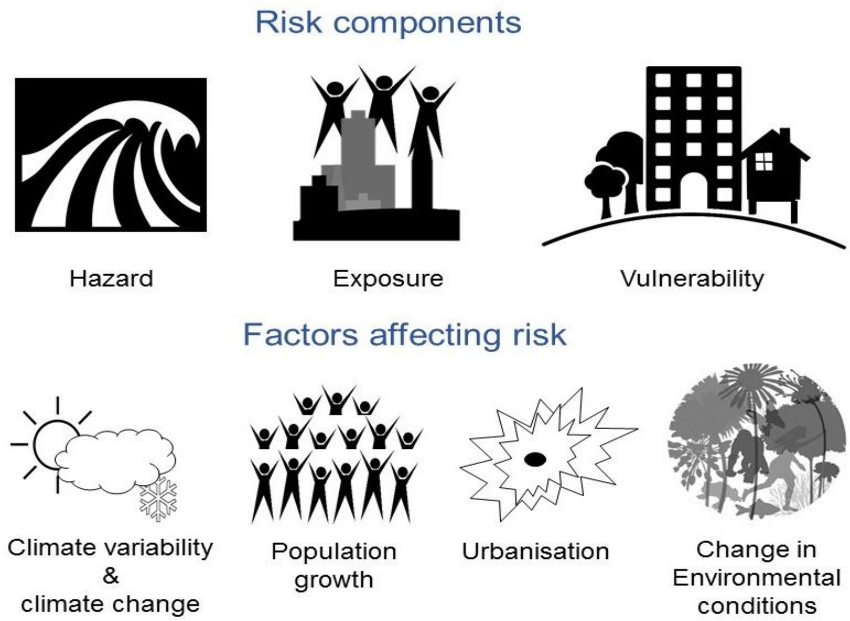

Figure 3. Flood risk components and influencing factors.

The urbanisation of BA has caused removal of wetlands, channelisation of waterways and an increase in impervious surfaces and runoff (Sejenovich & Cock Mendoza, 2000). Changes such as paving and the construction of railways and streets at right angles to the natural drainage flow have also undermined the capacity of the city to deal with flooding. Furthermore, landfill and urban development in BA have transformed the hydromorphology of the city, by altering natural stream channels, and their discharge to the La Plata River and the coastline.

Population growth and a lack of urban planning have also increased exposure to floods, because more settlements have been established in low-lying areas, such as the Matanza–Riachuelo Basin, with limited connections to drainage systems. Settlements in vulnerable areas have been motivated not only by the tight real estate market, but also by the BA city council, with monetary credits being offered on building, and housing support programmes such as Pro-Tierra, Pro-Casa and Pro-Lote (Clichevsky & Herzer, 2000). The city is also regulated by a flexible building code, with lack of control and enforcement manifest. Therefore, the exposure of the population and their assets to flooding has grown. All these issues have arisen not only in the city, but also in the suburbs, where dwellings have increased significantly in former wetlands of the Paraná Delta, which used to act as a buffer zone. Furthermore, deficient maintenance of the drainage system has meant the system cannot cope with changes to the city's infiltration capacity, the maximum rate at which the soil can absorb water (Sejenovich & Cock Mendoza, 2000; World Bank, 2016). The rainwater that cannot infiltrate into the ground due to impervious areas causes more surface runoff, which must be collected by drainage systems.

These issues are a direct consequence of city authorities' past tendency to accept floods as natural events that could not be mitigated or planned for (González, 2005; Koutsovitis & Goyeneche, n.d.; Sejenovich & Cock Mendoza, 2000). Throughout the years, environmental awareness and social concern about frequent flooding have increased, as well as public knowledge about structural and non-structural measures available for flood mitigation. These changes in perception have led to a slight improvement in flood prevention, mitigation and response measures. However, factors such as the city council's limited budget and the urgency to solve issues that are "more important" have delayed the implementation of flood mitigation strategies. Therefore, a rigidity trap in terms of ideological and economic factors has led to an unsustainable flood management regime.

Flood Modelling in Buenos Aires

Lecertua (2010) has developed a flood model for BA (Figure 4) to demarcate hazard zones in past and predicted flood scenarios for the years 1990, 2030 and 2070. The Lecertua (2010) model was based on the Re & Menéndez (2005) Río de la Plata two-dimensional (RPP-2D) hydrodynamic model of the La Plata River, which uses Navier–Stokes equations for shallow waters. Data from 1990–1999, collected at the BA water level station, were used to establish a baseline. Future scenarios for the years 2030 and 2070 have been based on the IPCC's A2 storylines for a future world, where no big socioeconomic changes are expected, the global population keeps growing, economic development is focused at the regional level and technological changes are slow to occur (IPCC, 2001a, 2001b; Lecertua, 2010). The IPCC projections for sea level rise, 19 cm and 50 cm for the 2030 and 2070 decades, respectively (IPCC, 2001a, 2001b), were incorporated into the Lecertua (2010) flood model.

The Lecertua (2010) BA flood model was based on the mean level of the La Plata River (0.80 m), as measured by the Naval Hydrographic Service during the 1990s, and a flood threshold (1.60 m), which corresponds to the maximum astronomical tide. Flow increases in La Plata River tributaries were not simulated in future flood scenarios because increases in flow of up to 30% do not have a significant effect on river flood levels in BA (Re & Menéndez, 2005). Wind patterns and future wind changes were analysed, however, because winds do play a large role in local flooding behaviour.

Lecertua (2010) obtained the bathymetry data of his model from digitised depths of the La Plata River (Administrative Comission of the La Plata River [CARP], 1989), databases and two naval charts (H-113 and H-116) provided by the Naval Hydrographic Service. The rugosity effect of the riverbed is only significant in the inner section of the river, where the depth is shallow, but not on the external section closer to the seafront. Thus, a uniform 0.015 Manning coefficient was used (Lecertua, 2010) in the model. The Lecertua (2010) model also used the parallels 35.8°S and 40.5°S, and the meridian 51.5°W, as mathematical oceanic borders, and the Argentinian and Uruguayan coasts as physical boundaries. Low-energy waves were assigned as the eastern border because their energy is smaller compared to energy contained by waves propagated along the continental platform (Re & Menéndez, 2005). The northern border was assumed to be non-reflective. Astronomical tides were reckoned for the southern border (Lecertua, 2010).

The results of Lecertua's (2010) hydrodynamic model were plotted on flood risk maps showing the height and duration of predicted floods for different recurrence intervals (2, 5 and 10 years). The digital terrain model (DTM) grid, used for creating inundation risk maps, consisted of 250 m-resolution cells. The maps were referenced to the Military Geographical Institute (IGM) datum. In addition, the local city council identified flood vulnerable areas based on historical data describing areas inundated during past high-intensity rainfall events (Government of the Autonomous City of Buenos Aires [GCABA], n.d.) (Figure 4).

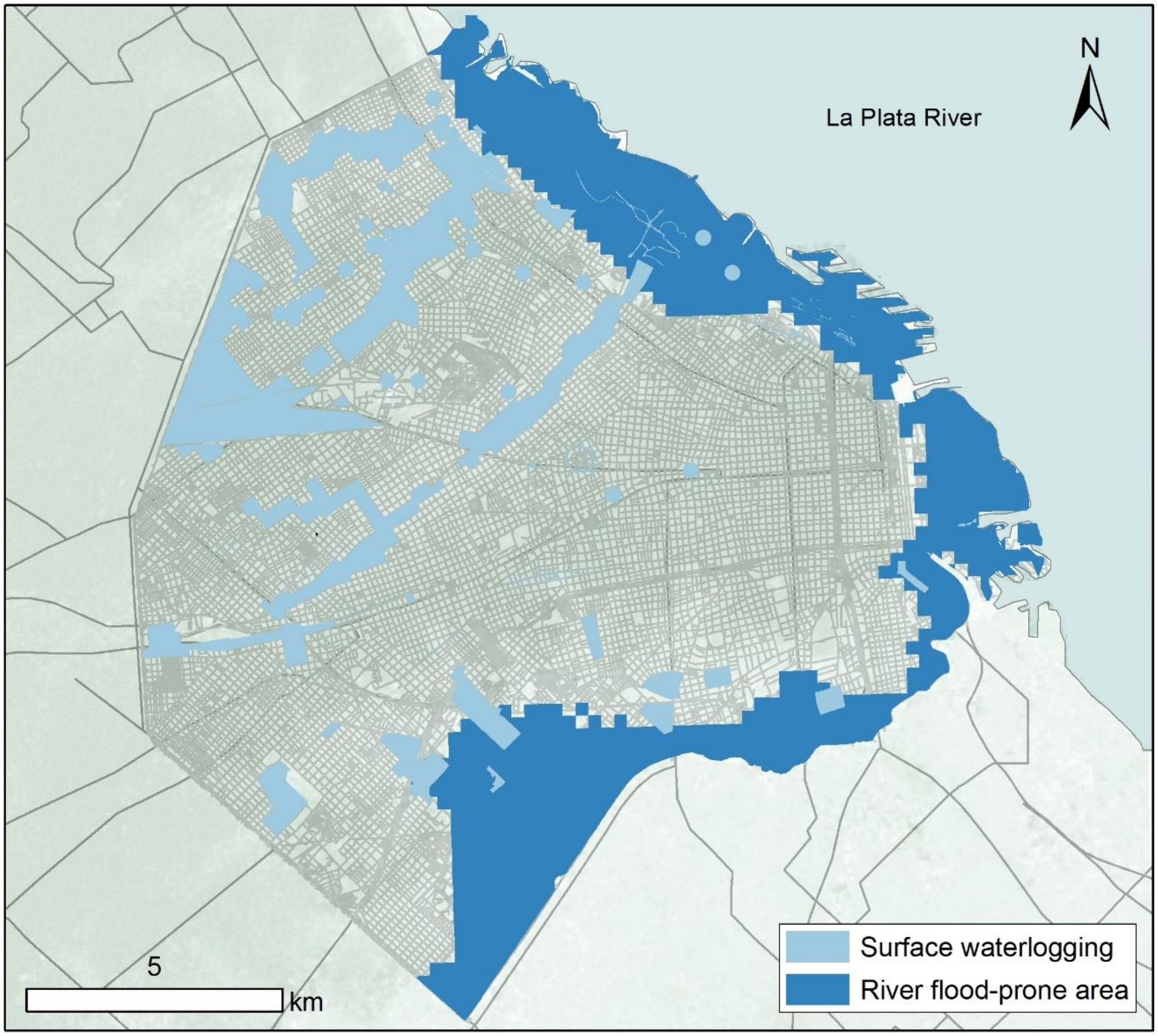

Figure 4. Areas in BA that are exposed to flooding by the La Plata River, or waterlogged by high-intensity rainfall, identified by a river flood model and the local council.
Note. Map created by the author with raw data obtained from https://data.buenosaires.gob.ar/dataset (GCABA, n.d). River flood model adapted from Lecertua (2010) with permission.

Flood Impact Assessment

Flood exposure comprises the social and built environment that can be affected by floods, which can change through time, for example, due to urbanisation or population growth. Herein, a review of various methods to quantify flood impacts on exposed assets is presented. However, the sheer variety and inconsistencies in estimation methods make comparisons difficult. For instance, disaster impacts in Argentina are usually recorded in DesInventar (UNISDR, n.d.), a Latin American database that collects information from the media, domestic databases and government organisations. Despite multiple sources, DesInventar is missing many records, and records include data collected up to the year 2009 only.

Damage to infrastructure lifelines and utilities. Impacts on utilities vary depending on flood parameters such as depth, velocity, duration, and sediment transport. Impacts also depend on the vertical location of electrical and mechanical equipment. Damage extent also depends on the timing and nature of management interventions, such as shutting down facilities. In addition, flood vulnerability is not the same for all components of all systems. For example, fresh water and wastewater systems are usually capable of resisting floods, so no severe damage is expected (Penning-Rowsell et al., 2005); however, pumping stations of the water-supply network are highly vulnerable (Reese & Ramsay, 2010). Floods usually cause interruptions to electrical and telecommunications services, however. Power outages in BA can last from a couple of hours up to several days.

Transport disruption. Damage to roads and traffic disruption affect transport networks and accessibility. According to Penning-Rowsell et al. (2005), flood impacts on transportation need to be evaluated carefully, especially when low-return-period floods disrupt a large portion of the road network. Return period is understood as the estimated time interval between events of a similar size or intensity (NIWA, n.d.). Reese and Ramsay (2010) maintained that impacts to the road network, such as inundation, erosion, scouring of road beds and shoulders, accumulation of debris or rubbish, and intensifying erosion and blockage of crossroads, tend to be smaller in comparison with damage to buildings and their contents. However, flow velocity and wave action do cause damage to roads. These are critical factors in flash flood areas, but not in floodplain areas common to BA. In floodplain areas, the damage to road infrastructure usually represents less than 1% of total direct, tangible damage (Messner et al., 2006). The clean-up costs of the affected road network can be based on data from Reese's 2003 study (as cited in Reese & Ramsay, 2010), which assumes a cost of USD 8.70 per m^2 of flooded road.

Impacts on the rail system are infrequent, except for cases of extreme weather, as described by Messner et al. (2006). For instance, on April 15th, 1940 in BA, the recorded tidal height was 4.44 m above the Riachuelo Tidal Datum (RTD), and water reached the Mitre Railroad, 500 m away from the coast, breaking some of its tracks (D'Onofrio et al., 1999). It then follows that rail disruption would be significant where main terminals, such as Retiro in BA, are exposed to frequent floods and disruption, or where rail disruption implies long alternative route diversions (Penning-Rowsell et al., 2005). Unfortunately, flood prevention or mitigation measures can rarely prevent rail transport disruptions (Penning-Rowsell et al., 2005).

A recent 2016 World Bank study has assessed traffic disruption costs in BA, but only in the Maldonado and Vega Basins. Flood effects on traffic were assessed by counting the additional time, fuel and distance that vehicles needed to travel to find alternative routes that were not blocked by flood waters (World Bank, 2016). Researchers measured the number of vehicles and their passengers crossing selected road intersections, and the distance required to find alternate routes from a specific intersection during the floods.

The monetary value of time wasted by people left without the means to move from a specific place was also evaluated by the World Bank (2016), based on the number of houses in the flooded areas, the average number of persons per household, the cost of the time lost and the duration of flooding at different recurrence intervals. The World Bank (2016) researchers assumed that 50% of the affected population would be in their houses, or going to their houses, at the time of the flood.

It should be considered that disruptions to traffic, and the resulting interference in production and supply chains, can also affect areas adjacent to flooded zones (Messner et al., 2006). The city of BA is one of the main transport and supply chain nodes in Argentina, so outlying areas rely on the smooth operation of its transport networks. Therefore, this research enlarges the analysis of transport disruption beyond the Maldonado and Vega Basins, and includes areas outside the city that depend on BA as a supply node. These outlying areas are highly vulnerable to flooding impacts as well, making their inclusion significant in the overall analysis.

Economic losses.

Vehicle damage. A study conducted for the City of Ryde, Australia (Bewsher Consulting Pty Ltd., 2009) measured vehicle damage by considering the average number of vehicles per household. Briene et al. (2002, as cited in Messner et al., 2006) assessed the cost of losses to private vehicles being driven at the time of the study based on market values of cars and linear depreciation. Pfluegner (2001, as cited in Reese & Ramsay, 2010) also proposed thresholds for different types of vehicle damage; they based their conclusions on laboratory tests. At 0.3 m, they found that water can reach the base of vehicle doors, damaging the floor, seats and interior fixtures, which represents a 25% loss; at 0.6–0.8 m, the electronic circuit is destroyed, and beyond that level, damage continues to increase, and a complete write-off can be expected.

The time of the flood is a critical factor in the calculation of vehicle damage, because at different times of the day, varying numbers are assumed to be on the road. Researchers believe that 25% of vehicles will be travelling during working hours, and 90% will be on the roads during non-working hours (Bewsher Consulting Pty Ltd., 2009). Despite these variances, sufficient advance warning might allow people to move their vehicles to safe areas and reduce the losses, no matter the time of day.

All the factors discussed above, which clearly affect vehicle damage estimates, such as average number of vehicles per household, depreciation, and flood depth and time, are considered in this research. In this thesis the influx of cars from suburban areas that enter the city daily is also considered to be a significant factor.

Damage to property and contents. The evaluation of direct or indirect flood damage to properties and their contents can be developed based on flood characteristics, such as the area flooded, flood depth, duration and velocity of the water (Reese & Ramsay, 2010), all of which generate different degrees of damage. Depth–damage curves (Figure 5) are useful for estimating the percentage of damage from floods, or the direct and indirect effects on different assets. Direct damage can be understood as a damage ratio based on full replacement cost (Remo et al., 2016), as repair costs in relation to replacement cost, or as a damaged state (Reese & Ramsay, 2010). Indirect damage relates to population displacement, loss of income, disruption costs and additional household expenses incurred by floods (Bewsher Consulting Pty Ltd., 2009).

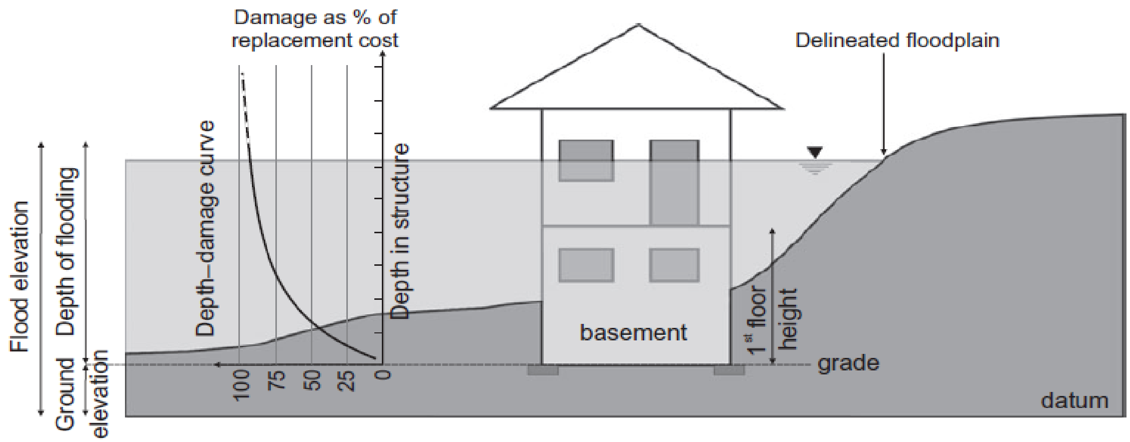

Figure 5. Depth–damage functions in relation to inundation depth (depth in structure) (Nastev & Todorov, 2013).

As stated by various authors (Merz, Kreibich, Schwarze, & Thieken, 2010; Messner et al., 2006; Reese & Ramsay, 2010), different types of depth–damage curves can be generated depending on the sources of information. Empirical curves are determined by using empirical data gathered from historical floods and the damage they caused, while expert evidence or damage data collected via "what-if" scenarios can help to create hypothetical or synthetic curves. The use of both types of curves reduces the limitations of each method (Reese & Ramsay, 2010).

Building categories (residential, commercial and industrial) and their contents also have significant influence on depth–damage curves. Structural costs are often estimated from publications that specify mean square foot costs for various types of buildings (U.S. Federal Emergency Management Agency [FEMA], n.d.). Content damage values are estimated by insurance companies from an average value, either a depreciated or a full replacement value (Briene et al., 2002 as cited in Messner et al., 2006), or from official statistics (Čihák et al., 2005 as cited in Messner et al., 2006). Other methods include the estimation of content value per square metre of living area (Meyer, 2005 as cited in Messner et al., 2006), or as a percentage of the replacement cost of the facility by building type (FEMA, n.d.; U.S. Army Corps of Engineers

[USACE], 2003). The Canadian version of Hazards U.S. (HAZUS) software, a tool for quantifying risks from natural hazards, considers the content damage value as 50% of structural values for residential buildings, 100% for commercial buildings and 150% for industrial buildings (Nastev & Todorov, 2013). The HAZUS approach is more suitable for BA, as no official data exist on content values or costs of damage caused by previous floods, differentiated between building uses.

Property damage reduction. As reported by Messner et al. (2006), property damage reduction estimates can be made as a function of flood depth, number of storeys, building use category (not individual buildings) and warning lead-time (e.g., < or >8 h). Warning lead-time is understood to be the time between when a warning message is issued by government agencies and the start time of the floods.

Flood warnings play an important role in decreasing residual risk to flood control infrastructure (Messner et al., 2006). Warnings allow people to reinforce or place temporary flood defences and to shift vulnerable house contents (furniture, computers and supplies) to a higher floor or second storey, thereby reducing economic losses. Even in buildings without second storeys, inhabitants can manage to move contents and reduce damage to them (Penning-Rowsell & Green, 2000; Smith & Ward, 1998).

Other methods have been applied abroad to estimate damage reduction, as in the City of Ryde, Australia (Bewsher Consulting Pty Ltd., 2009), where a fixed reduction factor (0.96), based on flood awareness and effective warning time (1 hour), is used. The calculation of a flood-reducing factor, which account, for example, for flood control infrastructure or warning time, is complicated, however, as people's behaviour plays a central role in social responses to flood warnings. Therefore, the response to warnings, and reducing factors, might differ between the Australian and Argentinian cultures. Furthermore, in accordance with Handmer (2000), social changes and technological improvements can alter the effectiveness of flood warnings. The quantification of damage reduction in monetary terms might lead to an oversimplification of the diverse responses to flooding warnings; however, it is a useful tool for the appraisal of flood management measures and warning schemes (Messner et al., 2006).

Post flood clean-up. Property clean-up time and costs can be estimated by evaluating property size and use, flood depth, damage ratio, hourly labour rate and post event average clean-up time. Average clean-up time and costs are quite diverse in the literature. For instance, average clean-up time after flood events in New Zealand is 12 days, based on a range of 2–40 days (Reese & Ramsay, 2010). Costs vary from NZD 12,400 for water levels lower than 0.1 m to NZD 21,700 for levels greater than 0.1 m (Penning-Rowsell et al., 2005). The Department of Environment, Climate Change and Water in New South Wales, Australia, has estimated a figure of AUD 4,000 (≈ NZD 4,350) per flooded house for clean-up and alternative accommodation costs (Bewsher Consulting Pty Ltd., 2009). Reese and Ramsay (2010) adopted a simple method based on the estimated clean-up time and an hourly labour rate per building category, which is more suitable for BA, where there are no official records of clean-up costs.

Emergency costs. Emergency costs are associated with emergency services and relief. Several studies have reported emergency costs as a percentage of total property losses. These estimations vary from 2.2%–10.7%, based on different sizes of flood-affected areas, and flood characteristics (Freistaat Sachsen as cited in Pfurtscheller & Schwarze, 2008; Sachsen-Anhalt as cited in Pfurtscheller & Schwarze, 2008; Penning-Rowsell et al., 2013; Penning-Rowsell & Wilson, 2006). These values will be considered for BA, as emergency costs from previous flood events have not been made publicly available.

Indirect flood losses. Indirect flood effects are hard to estimate, mainly because of the scarcity of accurate data and business confidentiality issues. Penning-Rowsell et al. (2005) have suggested avoiding the topic entirely, because indirect impacts do not represent a significant value. Indirect impacts tend to be smaller than direct impacts, usually less than 25% or even 10% of total direct impacts costs; greater indirect damage has been registered when traffic disruption and clean-up costs were large (Reese & Ramsay, 2010). This thesis will focus on direct effects and will not quantify indirect impacts.

Emergency Response and Evacuation Different actions can be implemented to address risk, such as doing nothing, avoiding, reducing, transferring or mitigating the risk. Emergency response is an effort to mitigate the risks inherent in impacts caused by an incident, and can include firefighting, administering medical treatment, rescue or evacuation (U.S. Department of Homeland Security, n.d.). Diverse types of evacuation can be carried out on a small to a large scale, pre- or post-event, immediate or pre-warned (U.S. Department of Homeland Security, n.d.).

In an evacuation, the number of people looking for shelter can vary, because only a percentage of displaced people will search for public shelter. Usually these are low-income people. Some people will try to find temporary shelter despite minimum or no damage to their homes (FEMA, n.d.). The number of evacuees can be estimated based on flood level (Penning-

Rowsell et al., 2013), or by using FEMA's logarithmic function, which considers building damage and the time people must spend in temporary accommodation while repairs to their former homes are carried out. If building damage is less than 10%, no displacement is expected; if the damage is greater, then displacement can take from 30–365 days (FEMA, 2001).

Collecting post flood event data in BA would be valuable as a test of the 10% damage threshold, which proved to be lower in the 2004 Manawatu–Hutt Valley, New Zealand floods (Reese & Ramsay, 2010). Relocation costs can be derived from the number of evacuated householders remaining in temporary accommodation (Penning-Rowsell et al., 2013), or as a function of house floor area, rental costs per day, disruption costs and the probable evacuation time per damage state, which refers to the level of damage to buildings, as per HAZUS (a multi-hazard loss estimation software and damage database) protocols (FEMA, n.d.). Penning-Rowsell et al.'s (2013) approach seems more appropriate for BA because of the limited data available from past flood events in and around the city.

Pre-event flood modelling can optimise evacuation time and clearance. The complexity of modelling potential evacuation routes and zones can be addressed by the interfaces between different disciplines — transport planning, engineering and social sciences (Alabdouli, 2015). Various evacuation models have been proposed for different hazards. The most commonly used are agent-based models (ABMs) and geographic information system (GIS) analyses, such as the least cost path distance (LCPD) model. The ABM models explore interactions between and decision-making processes of individuals or organisations (D'Orazio et al., 2014; Medina, Sanchez & Vojinovic, 2016; Yin et al., 2014). The LCPD model ignores social variables, and only describes environmental factors such as land cover, slope, or incline, length and energy (e.g.

fuel) to estimate the minimum cost of travel associated with evacuation (Le, 2016; Wood, Jones, Schmidtlein, Schelling, & Frazier, 2016).

In BA, evacuation centres have been established at sports complexes (GCABA, 2009), but no published literature describes evacuation models for the city. Despite the lack of evacuation models, improvements have been made in the legal framework. City authorities have developed an emergency management plan (GCABA, 2009), which establishes the responsibilities of each governmental agency during an emergency. In addition, a dedicated emergency coordination and control centre (CUCC) has been set up. At the same time, Argentina is currently developing a national plan for disaster risk resilience (DRR).

The Risk Management Process

Risk management provides a framework to deal with the complexities of risk assessment and risk treatment, process of selecting measures to modify risk, in BA. It involves various phases that provide structure to the process and make it repeatable internationally. Risk management is also scientifically based, contributing to its transparency and credibility. As defined by Standards New Zealand (2009), the risk management process includes stages that are retrofitted by continuous communication, consultation, monitoring and review (Figure 6).

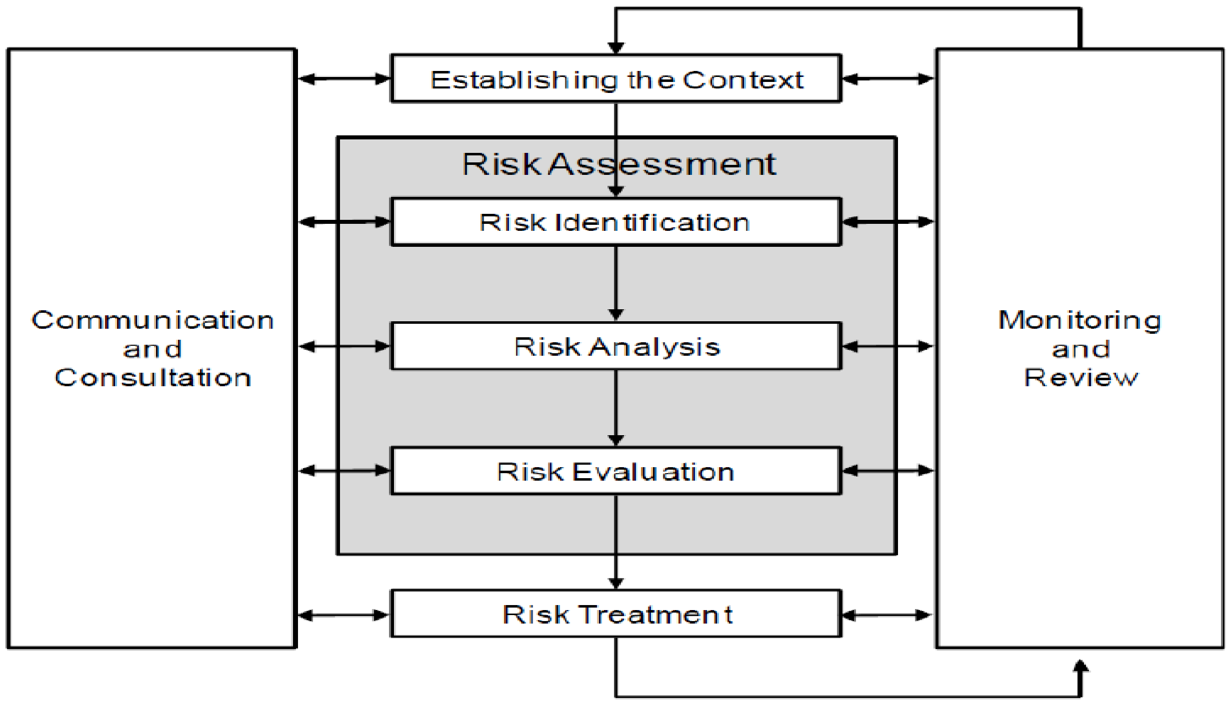

Figure 6. The risk management process (Standards New Zealand, 2009).

There are three main commonly accepted risk management phases (Establishing the context, Risk assessment and Risk treatment), which are supplemented by Communication and consultation and Monitoring and review, outlined below.

Establishing the context implies the identification of clear objectives and scope of the study or project; the nature of the risk; quantification units and methods; the planning framework (systems, protocols, national or local regulations); authorities and responsibilities; risk implications in the social, economic, environmental and political fields; and values associated with assets at risk.

Risk assessment includes the identification, analysis and evaluation of hazards, risk extent, and nature and vulnerability of exposed assets. Such assessments include hydrological and climate change risk maps, mapping of vulnerable buildings and areas such as slums, hospitals, schools and retirement homes (GCABA, 2015a; MAyDS, n.d.).

Risk identification incorporates diverse methods to identify risks, which at this stage are generally qualitative. The risk identification toolkit includes preliminary hazard analysis (PHA), the structured what-if technique (SWIFT), hazard and operability studies (HAZOPS), the failure mode and effects analysis (FMEA), hazard mapping and interviews. An evaluation of objectives, expectations and necessary resources is also developed. The input of different stakeholders is beneficial at this stage, as diverse stakeholders can provide local knowledge and first-hand experience. Furthermore, interaction with the community can help to build trust, which will be beneficial when the community must put action plans into practice later.

Risk analysis includes a quantitative, qualitative or semi-quantitative analysis, depending on the method and unit measurements selected when establishing the context. Available resources and data play important parts in determining the most suitable method for evaluating risk significance and any residual risk.

In this thesis, we have performed a semi-quantitative analysis to assess BA infrastructure lifelines and critical utilities disruption. This type of analysis was the most appropriate choice because data describing utilities service areas and infrastructure lifelines in BA are lacking. We measured lifeline and utilities disruption by assessing potentially affected populations living around assets prone to flooding.

Quantitative analyses can be developed by using various approaches, including deterministic and probabilistic analyses. The Lecertua (2010) BA flood model that underpins this project was based on a probabilistic hydraulic model, which was developed using historical La Plata River level data. These data included quantitative values describing frequency, duration and distribution of flood events. Lecertua (2010) also used the IPCC A2 scenario (IPCC, 2001b), in which the mean sea levels increase by 19 cm in the year 2030 and by 50 cm in the year 2070, to determine future flood scenarios. Flood levels served as indicators of damage to building structures and contents.

Risk evaluation is a process whereby risk is evaluated by an objective method. The objective is to minimise the effects of personal perceptions on risk analyses. Personal, subjective perceptions are influenced by social values, fears, unfamiliarity and the need for personal control. Perceptions of uncontrolled risk, voluntary or involuntary risk, event frequency and event size are also subjectively derived conclusions that can be removed from risk analyses through careful evaluation. The ultimate goal is to determine whether a risk is acceptable, tolerable or intolerable, depending on the context evaluated in the first phase.

The concept of tolerable risk was developed by Layfield (1987). A tolerable risk is defined as a risk that people are prepared to tolerate in order to receive benefits. Following the Layfield (1987) as low as reasonably practicable (ALARP) criteria, risk levels can be classified as intolerable or tolerable — within the ALARP region, risks are acceptable.

The objective risk evaluation process provides valuable information for the development or revision of strategies and action plans, as well as for decision making, because resources and time can be prioritised to reduce unacceptable risks. Risk managers can assist regulators, planners and communities at risk by organising statistics, thresholds, comparisons and alternatives into a plan for dealing with flood risk.

Risk treatment occurs once experts assess and classify risk against set criteria. Decisions are made in order to “treat” the risk to various degrees. Direct and indirect costs, and benefits and opportunities to all parties, are evaluated. Risk treatment can include different type of actions, such as:

- *Avoidance*. Actions taken directly on the hazard or exposure can avoid risk. This might imply restructuring a whole project, or changing some of its parameters, to avoid or scale down the risk to acceptable or tolerable levels. For instance, land developers can modify the location of a new project to avoid low-lying areas that are prone to flooding. In the south of BA, vulnerable communities were relocated to promote native riparian planting and restore the floodplain area (GCABA, 2015a).
- *Reduction*. Reduction describes actions taken to diminish the likelihood of the event, for example by constructing flood, storm surge and wave protection. For example, the breakwater protecting BA port.
- *Mitigation*. Mitigation actions reduce the impacts of the event. Mitigation can include using water-resistant construction materials for infrastructure and building projects, sandbagging properties or encouraging infiltration by increasing the permeable area (e.g., the use of green roofs in government buildings in BA) (GCABA, 2015a).
- *Transfer*. A community can share risk between various parties, who can manage potential consequences as a group. Risk quantification can help in this transfer process to ensure risk allocation is not done subjectively or arbitrarily. One of the parties compensates the other after a flood event because a previous exchange of benefits occurred when the two parties faced the risk together. For instance, the community, the city council and insurance

companies can allocate flood risk between them, which allows them to better manage impacts by sharing resources. Currently in BA, standard household policies do not include flood coverage, which have to be especially requested by the insured (Barachetti, 2016).

- *Doing nothing*. In this scenario, risks and resultant impacts are accepted, so measures to combat them are not implemented. This approach was adopted until recently, since the BA council used to only respond to emergencies (González, 2005; Koutsovitis & Goyeneche, n.d.; Sejenovich & Cock Mendoza, 2000).
- *Structural measures.* Coastal defences and floor level rises in the La Boca neighbourhood of BA (Barros et al., 2006), vertical drainage wells in the Matanza–Riachuelo Basin (Golder Associates & Deltares, 2017), increased drainage system capacity (e.g., in the Maldonado, Vega and Medrano Basins) and retention ponds in Sarmiento Park, BA (GCABA, 2015a) are all good examples of practical risk treatments.
- *Non-structural measures*. In the social arena, BA City council staff have trained vulnerable groups and BA public agencies to respond to floods. They have also assisted with native plantings around flood-prone areas. In addition, authorities have arranged the relocation of vulnerable communities living by the Riachuelo River, and have created the Communication and Environmental Education Programme known as "PROCEAH" (GCABA, 2015a). Updates have been made to the BA urban (Ministry of Urban Development and Transport [MDUyT], 2017a) and emergency management plan (GCABA,

> 2009), and new institutional groups have been formed to deal with flood risk (e.g., the Committee for Emergency Attention and the Flood Risk Management Council). The implementation of a programme to monitor water levels in the BA drainage system, and the Hydrometeorological Observation, Vigilance and Alert System known as "SIHVIGILA", have contributed to improving flood prevention measures in BA.

Monitor and review is performed continuously during the risk management process to calibrate models and to test the appropriateness of decisions taken during each stage as new regulations, information, technology or flood models become available. Evaluating if goals are being achieved can also indicate the necessity of reviewing the risk management process. We performed a review of risk concepts in this thesis by studying existing published literature and regulations.

Communication and consultation with various stakeholders can enrich the whole risk management process, as it allows identification of the needs and perspectives of the community, or risk management organisations. Consultation also allows people involved to appropriately assess risk, and provides them with suitable risk treatment options. In BA, this phase has included consultation with local authorities (the Undersecretary of Emergencies, the General Directorate of Emergency Planning and Coordination of Firemen and the Emergency Coordination and Control Centre); and international contributors including BA and Canterbury Civil Defence; RiskScape developers (GNS Science and the National Institute of Water and Atmospheric Research [NIWA]); British Columbia (BC) Housing Canada; and the University of Canterbury, New Zealand. Communication with both local and international risk managers has fostered a broad understanding of the BA risk management approach in light of successful experiences that have been implemented overseas, which can be tailored to BA's need to improve risk management.

Research Aims and Objectives

The aim of this research is to examine flood vulnerability and response capacity in BA, Argentina under current conditions and in future scenarios. The principal objectives are:

- To determine flood impacts on buildings and infrastructure lifelines under current conditions and future scenarios that consider sea level rise (Chapter 2).
- To identify which factors (e.g., land price or housing density) have the greatest effect on increasing flood spatial vulnerability (Chapter 2).
- To characterise populations exposed to floods and to propose evacuation routes for their use in emergencies (Chapter 3).
- To determine if any current BA emergency and urban plans increase flood impacts or undermine the emergency response capacity of BA in any way (Chapters 2 and 3).
- To propose appropriate flood mitigation measures for BA under current conditions and in the face of projected flood impacts resulting from sea-level rises projected for the 21st Century (Chapter 4).

Research Approach and Thesis Structure

This thesis is structured as four chapters (Figure 7). Thesis structure mirrors the three main stages of the risk management process itself (Establishing the context, Risk assessment and Risk treatment). Chapter 1 describes the context of the project, the study area, aims and objectives. A review of previously published literature covers the following topics: flood hazards in Buenos Aires, flood modelling, impact assessment methods, emergency response, evacuation and the risk management process.

Chapter 2 focuses on flood impacts in Buenos Aires and is divided into three topics: 1) determination of flood-prone areas; 2) discussion of damage to infrastructure lifelines and utilities; and 3) exploration of economic losses, which include damage to buildings and their contents and vehicles, and post-flood clean-up and emergency costs.

The La Plata River flood model, statistical information and georeferenced data describing infrastructure lifelines, critical utilities and buildings are used to identify the flood-prone areas and exposed assets. Also used was available local information to determine damage costs and the spatial distribution of flood damage. A quantitative risk analysis was subsequently performed in ArcGIS 10.3, a geographic information systems (GIS). Depth–damage functions were used, which express flood depth and damage as a percentage of replacement cost, to estimate the cost of damage to BA buildings and contents. Comparisons were made according to building use category, neighbourhoods, risk control methods and flood scenarios.

Outputs of impact modelling, such as maps, tables and graphs showing building damage, lifeline disruption and flood-exposed areas, were used to evaluate flood risk for BA. Aspects such as colour schemes (Harrower & Brewer, 2003), plus quantitative risk information, were considered to facilitate the interpretation of maps and figures, as per established methodology (Rakow, Heard, & Newell, 2015).

Chapter 3 explores exposed populations in BA, their evacuation and specific emergency responses. In the risk identification phase, populations in flood-prone areas of BA were characterised quantitatively, based on demographic variables (e.g., gender, age, income and education level). An evacuation probability model based on flood depth was adapted to the local data available in BA to estimate the number of evacuees per neighbourhood in each flood scenario, and costs of temporary accommodation for the first several weeks following a flood event. Factors that increase flood vulnerability and influence population displacement were also analysed. Vehicle and pedestrian evacuation routes for BA were produced using the Network Analyst tool in ArcGIS 10.3 to estimate evacuation times and the number of evacuees that will arrive at different destination points.

A review of BA risk treatment strategies established in the urban and emergency planning framework, and interviews with officers in the local BA council and civil defence organisations, were also carried out to better understand the risk planning framework and its influence on BA emergency response systems. Fire stations' responses in scenarios with and without floods were analysed to better understand how flooding can disrupt traffic and emergency responses. Fire stations and staging point service areas were evaluated together to estimate how flood response in BA can be improved. Maps are used to show evacuation routes and the location of emergency facilities, while graphs provide information on evacuation times, evacuees and temporary accommodation costs. Uncertainties, data limitations, alternative methodologies and potential improvements are considered, as in Chapter 2.

Chapter 4, the conclusion of this research, is a review the main body of the work, and contains general recommendations to further develop the topic. Successful experiences that have been implemented overseas and that can be tailored to BA's needs to improve risk management are discussed. In addition, specific future research in the area of flood risk management is recommended, particularly for BA.

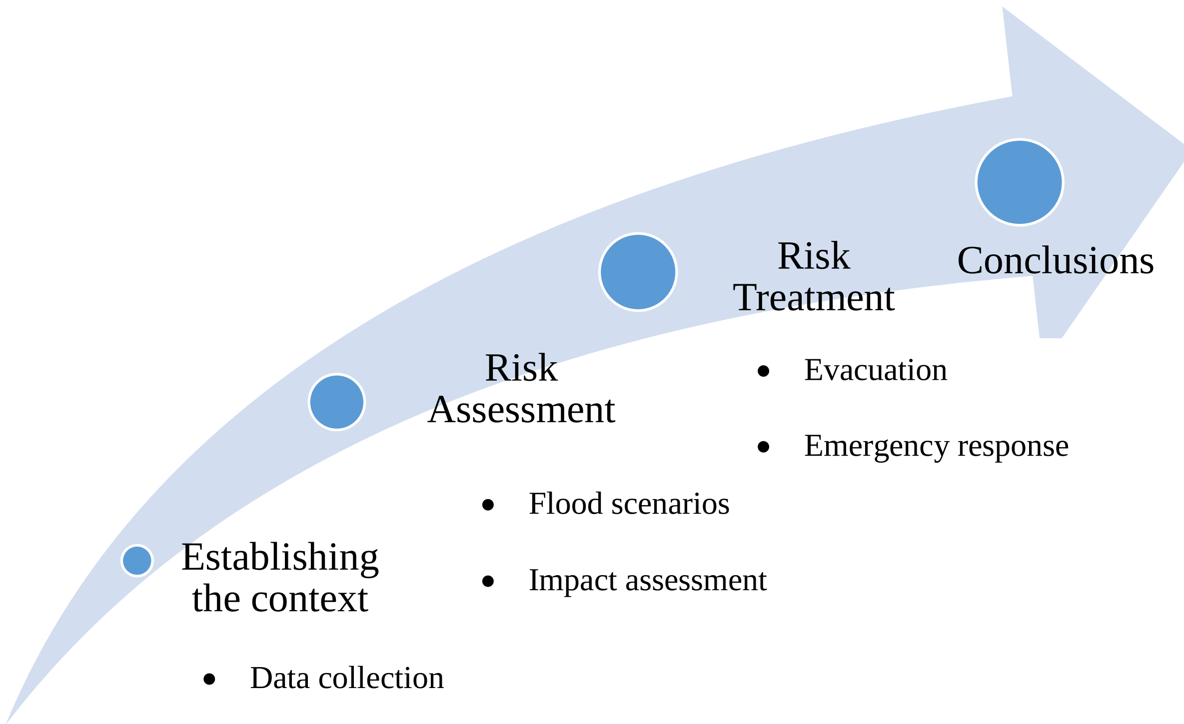

Figure 7. Summary of thesis structure based on the stages of the risk management process.

Chapter 2

Characterising Flood Losses: A Methodological Comparison

Introduction

Between 1984 and 2004, BA suffered 37 flood events (World Bank, 2005), equating to more than one event per year and losses in millions of USD. In April 2013, for example, flood damage was in the order of USD 300 million (World Bank, 2016). Natural and anthropogenic processes combined to result in flood vulnerability being more significant than in the past (Lecertua, 2010).

Floods in BA occur as a result of two main natural causes: high-intensity rainfall and high tides affecting the La Plata River, usually exacerbated by the infamous Sudestada winds. Furthermore, the low gradient of the BA plains hampers water drainage (Clichevsky & Herzer, 2000). Climate variability has aggravated the issue: changes in wind intensity and average annual rainfall have increased impacts. Sea level rises (1.6 mm/year) have also negatively affected La Plata River flood dynamics (D'Onofrio, Fiore, & Romero, 1994; Lanfredi, Pousa, & D'Onofrio, 1998).

These natural processes are exacerbated by urbanisation, which includes a gradual elimination of wetlands, armoured channelisation of waterways, and increases in impervious surfaces and associated runoff. Population growth in BA has also increased vulnerability to floods, as more settlements have been established in low-lying areas with limited connections to functional sewage and water drainage systems; such systems are insufficient to cope with high-intensity rainfall associated with even a 2-year flood recurrence (GCABA, 2014). Settlements in vulnerable areas have been driven not only by the real-estate market, but also by credits and housing programmes offered by the local BA council (Clichevsky & Herzer, 2000). Even though the city is mostly developed, individual properties are still being replaced by multi-storey buildings; thus, higher population density and increasing vulnerability can be expected in the near future. A flexible building code and a lack of control and enforcement have also contributed to increasing flood vulnerability.

The fact that a large coastal area of BA is within 5 m of mean sea level (Re & Menéndez, 2005), and that the city is the most heavily populated area in the country, implies that many people and their properties are jeopardised directly or indirectly by floods. Therefore, there is a need to examine flood impacts in BA under current conditions. It is also pertinent to account for projected impacts of climate change, sea level rise and population growth in order to improve land-use planning and emergency management. To wit, an assessment of flood damage can be an informative tool for many stakeholders, including the following: governments, who are evaluating policy and the cost–benefit ratios of flood mitigation measures; emergency managers, who need to know which areas are most endangered; insurance companies, who want to quantify flood risk and assign insurance premiums accordingly; and private landowners, who want to compare the costs of flood insurance or ask for damage compensation (Messner et al., 2006).

Consequently, the aim in Chapter 2 is to characterise flood impacts by using two approaches coupled with a damage reduction factor. Furthermore, a flood loss index (FLI) is developed, which allows comparison of methodological approaches, to propose rational, well-formulated flood mitigation strategies.

Study Area

The city of BA is located on the “Pampas Plains” of BA Province, on the East Coast of Argentina, and the city is divided in 48 official neighbourhoods (Figure 8). The city occupies

200 km^2 and is surrounded by the Riachuelo River to the south, and the La Plata River to the east, which is one of the main sources of flooding. The city is the largest in the country (with 3 million inhabitants), and 8.4% of its population resides in the officially demarcated flood inundation area. As a centre for commerce, BA contributes 24% of GDP to the national economy (World Bank, 2016).

Between 1880 and 1930, the first wave of metropolitan expansion took place. The city was chosen as the country's capital, which motivated the construction of the transport network in the central business district, located on the banks of the La Plata River. A mass migration process took place until the 1930s, which led to an increase in population, land subdivision and the development of basic infrastructure. Floods were an issue already in those years, because existing infrastructure did not take into account land topography. Until the mid-19th Century, the areas affected by storm surges were not fully occupied, except for the downtown area of BA, which was later protected by flood-mitigating infrastructure (Barros et al., 2006), including riparian protections and the addition of substantial landfill. In the 20th Century, urbanisation continued to occur at pace, with the emergence of slums, mainly in the south of BA.

In contrast to other cities in the U.S. and Israel, where wealthy people tend to build on higher ground (Felsenstein & Lichter, 2014), low-lying areas in BA are now inhabited by people of medium–high socioeconomic levels, particularly within the neighbourhoods of Nuñez, Belgrano, Palermo and Villa Crespo (Clichevsky & Herzer, 2000) to the north. Other lower-socioeconomic neighbourhoods, such as La Boca and Barracas to the south, are also frequently affected by inundations (Sejenovich & Cock Mendoza, 2000). Figure 8 is a fully detailed map of BA neighbourhoods.

Residential housing is the largest exposed asset, in comparison to non-residential buildings. The city has approximately 1,426,438 residential properties, 227,088 commercial premises and 2,672 industrial buildings (GCABA, n.d.).

Figure 8. Location of BA in South America (red dot, top left insert), and the city's 48 neighbourhoods.
Note. Satellite image obtained from Geoeye and raw data from https://data.buenosaires.gob.ar/dataset (GCABA, n.d.), projected in Posiciones Geodesicas Argentinas (POSGAR) 2007.

Methods

For this project, a flood damage assessment framework was developed using georeferenced data and depth–damage curves. Given that there are no post event data from BA floods that can be used for calculating flood damage functions, the analysis relies on the Lecertua (2010) BA flood model, existing socioeconomic data and geographic information about the city's infrastructure (Table 1), a dataset also used in other previously published studies (Karamouz et al., 2014; Mohammadi et al., 2014; Yang et al., 2006).

Table 1

Datasets Used to Generate a Flood Assessment Framework Specific to Buenos Aires (BA)

Dataset	**Source**
BA flood model	Lecertua, 2010
Land use, census GIS data	GCABA, n.d. (https://data.buenosaires.gob.ar/)
Statistics (land and hotel prices, transportation figures)	Buenos Aires Ciudad, 2016 (http://www.estadisticaciudad.gob.ar/eyc/)
Vehicle values	ACARA, 2017 (http://www.acara.org.ar/guiaprecios/precios.php)

Delimitation of flood-prone areas. The extent of flood-prone areas was calculated based on the Lecertua (2010) BA model for floods of different return periods, the estimated time interval between events of a similar size or intensity. ArcGIS 10.3 was used to delimit the area.

Damage to infrastructure and utilities. The damage assessment of lifelines and utilities includes an evaluation of the populations affected by direct flood effects on key infrastructure and services areas (Figure 9). Having and disseminating information on the disruption of services is vital for city authorities, because it can encourage timely evacuation, even if households are not yet flooded. Accurate information about disruptions to infrastructure and utilities can also prove key to emergency managers who need to know how many people will look for respite facilities outside the flooded area.

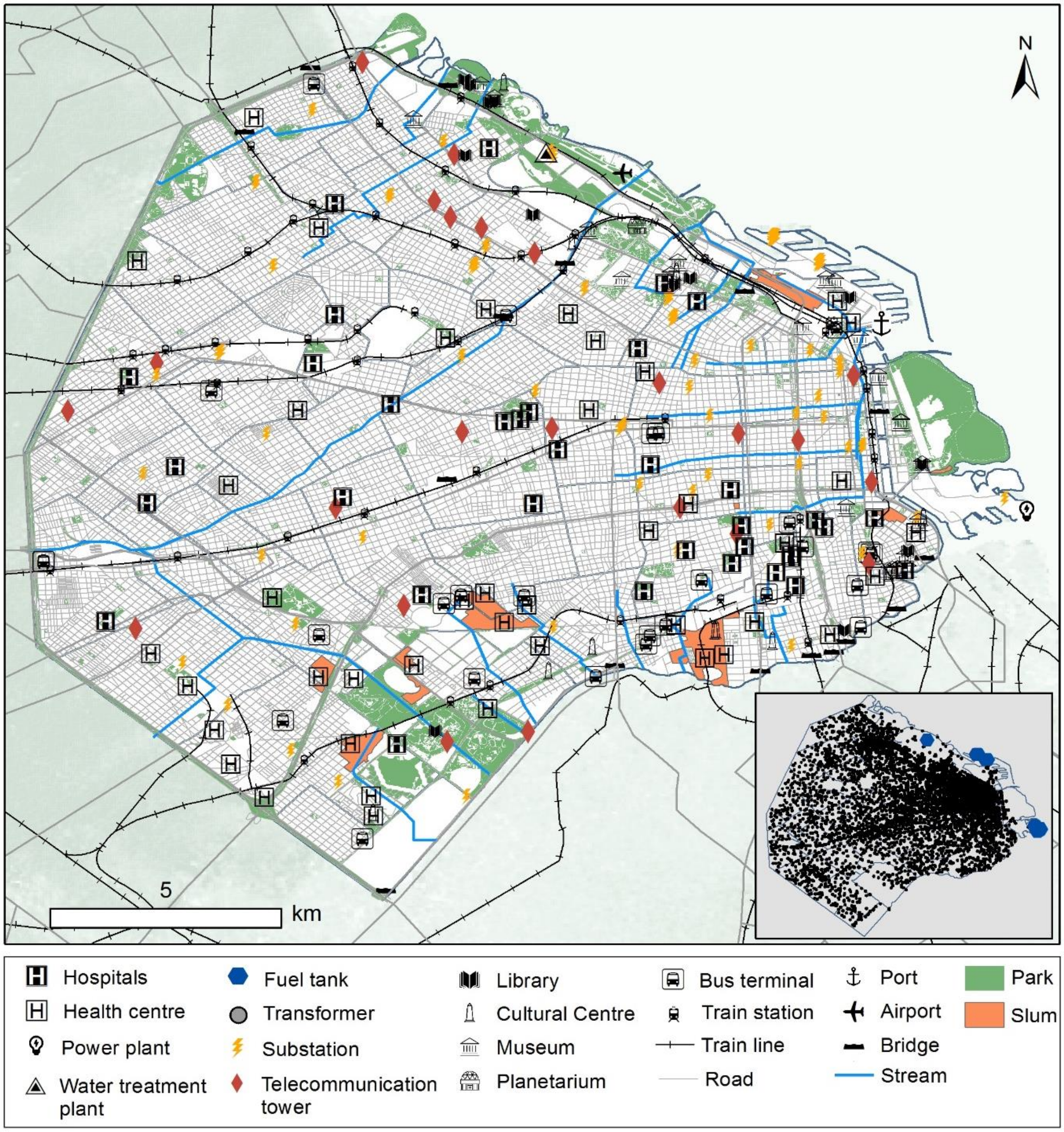

Figure 9. BA infrastructure lifelines and utilities. Inset shows fuel tanks and transformers (GCABA, n.d.).

Water and gas. Unfortunately, no detailed information about gas, water, wastewater, or stormwater systems in BA is publicly available; thus, a detailed evaluation of flood impacts on these facilities for the purposes of this research was not possible.

Telecommunications, power and health. Data on telecommunications towers, thermal power plants, electricity substations, hospitals and health centres operating in BA were publicly available, and the effect of flooding on these lifelines was estimated using the BA-specific flood model and census data. In each instance the number of potentially affected people was estimated within a 1 km radius of the flooded infrastructure.

Transport disruption. Flood effects on the BA road network were analysed based on their connectivity with suburbs and industrial areas, as such linkages might impact on supply chains and commuters. Road damage was not assessed per se, because impacts on roads are mainly produced by flow velocity and wave action, which are critical factors in flash flood areas, but not in flat areas like BA. Furthermore, damage to road infrastructure usually represents less than 1% of total direct, tangible flood damage (Messner et al., 2006).

For the purposes of this project, disruption to the transport system was assessed by using statistics describing passengers travelling by train, bus, plane or ferry (GCABA, n.d.-a). How maximum flood duration affected each means of transport in different flood scenarios was estimated. Economic loss estimations were calculated using 2017 ticket values, and average number of passengers per hour.

Utility interconnections. Due to difficulties inherent in characterising the interconnection of utilities, the indirect effects of utility interdependencies are not encompassed by this study. For example, fuel is needed for transportation, and transportation and road access are critical to reach sites where humanitarian aid or repairs are being carried out; electricity is required for pumps and telecommunications, and telecommunications are vital for emergency responses.

Cultural activities and the environment. This research also encompassed impacts on cultural activities. The aim was to evaluate the disruption to BA tourism and cultural life. Fuel tanks and electrical transformers were located and counted to identify tourism or culturally significant areas that might be exposed to flood or fuel contamination. The inclusion of cultural and environmental aspects enlarges the scope of the analysis, which would otherwise have been limited to a narrow analysis of infrastructure and direct, tangible damage.

Economic losses. In this study, the estimation of economic losses from flooding includes vehicle, property, inventory, clean-up and emergency costs.

Vehicle damage. Calculations of vehicle damage were based on three indicators: average number of vehicles per household (Ministry of Transport [Ministerio de Transporte], 2009) in flood-prone areas; the vehicles' value after 8 years' depreciation (82% of sale price) (Penning-Rowsell et al., 2013), using the four best-selling cars in Argentina in 2016 for calculations (Association of Car Dealers of the Argentine Republic [ACARA], 2017); and flood depth. Two scenarios were considered, following the Bewsher Consulting Pty Ltd. (2009) approach, floods during working hours (40 hours per week), and floods during non-working hours (128 hours per week), where 25% and 90% of cars are on the road, respectively. It was assumed that cars per household in flood-prone neighbourhoods were inundated to equal depths unilaterally, either at 0.3 m or at 0.6 m, which represents 25% and 100% damage, respectively, based on Pfluegner (2001, as cited in Reese & Ramsay, 2010). Cars from suburban areas entering the city daily (except trucks and buses) were assumed to traverse flood-prone areas. Losses of commercial vehicles were not included in this study, since these vehicles are considered to be a commercial property's direct loss.

Property and contents damage. Generic depth–damage curves developed in previously published literature and specific to coastal urban areas similar to BA were applied to evaluate flood impacts on buildings and contents. Contents value was calculated as a percentage of structure value. Curves were used from the micro-scale risk evaluation of flood-prone coastal lowlands in Schleswig-Holstein (MERK) (Markau, 2003 as cited in Sterr et al., 2005) in Germany, plus an alternative to the HAZUS platform used in the U.S. (Karamouz et al., 2016) (Figure 10 to 12) to evaluate which method better fitted the study area. Residential, commercial and industrial land uses were included in the analysis.

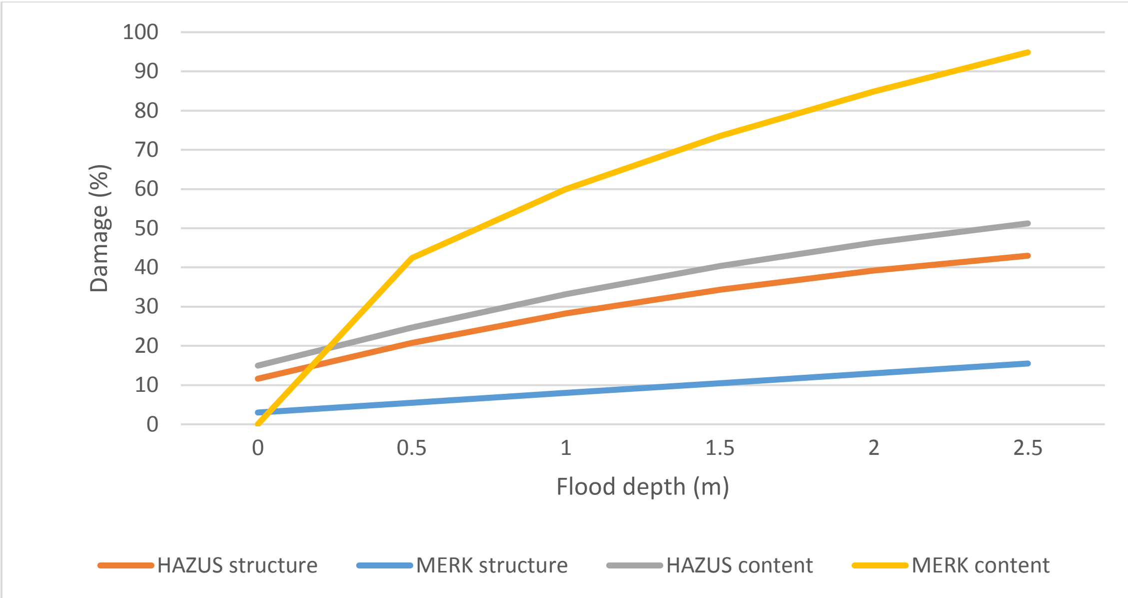

Figure 10. Depth–damage curves for residential land use.

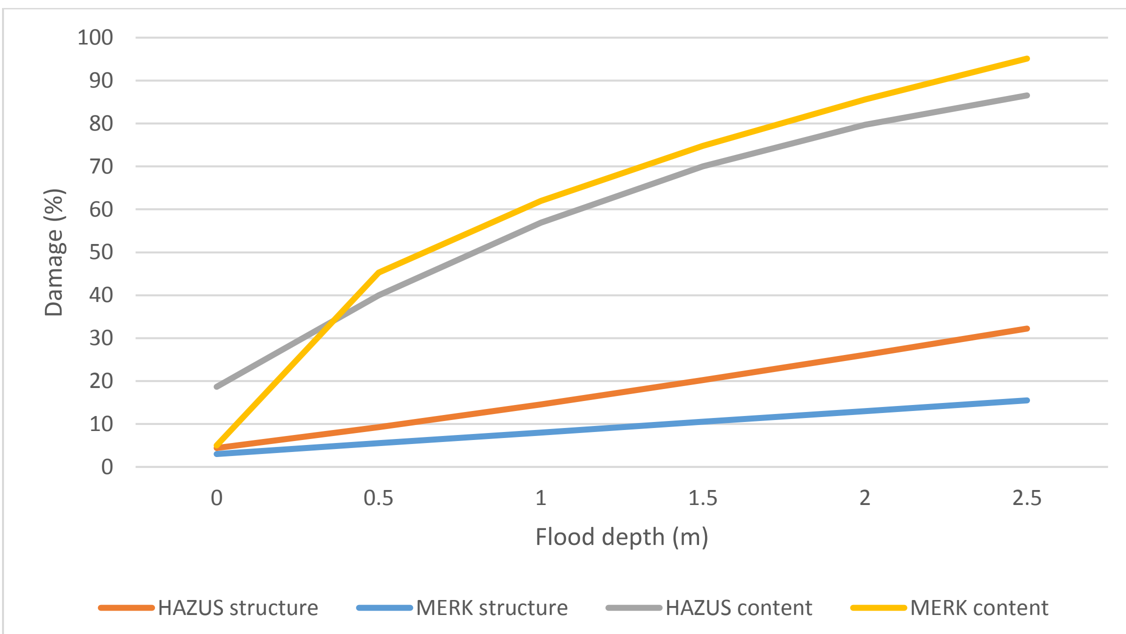

Figure 11. Depth–damage curves for commercial land use.

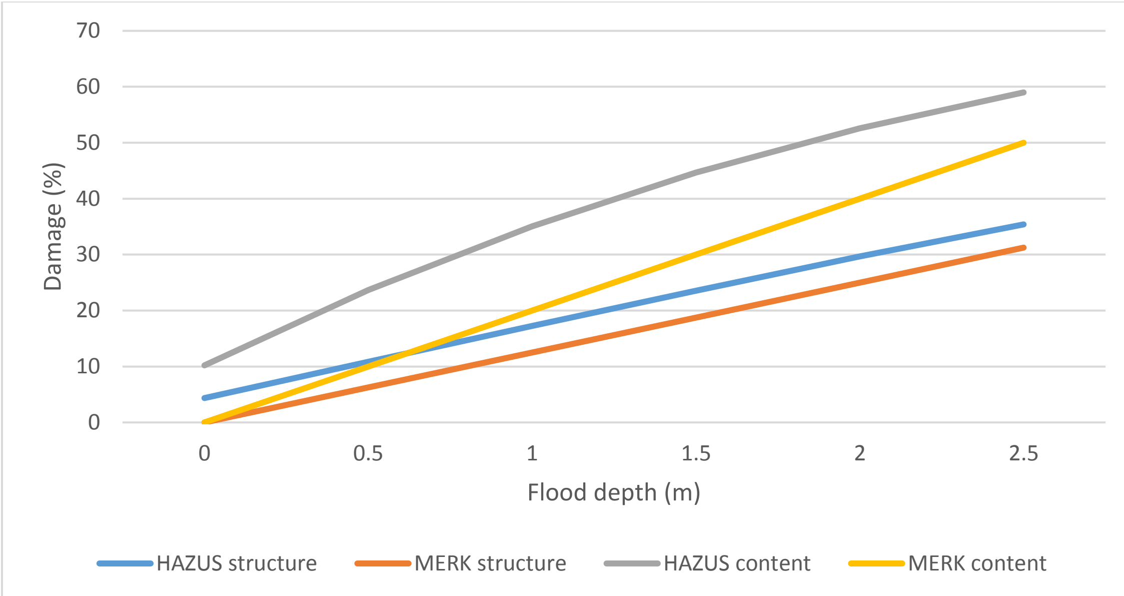

Figure 12. Depth–damage curves for industrial land use.

Given that the latest flood risk assessment study developed in BA (World Bank, 2016) did not establish differences in terms of building use category, specific depth–damage curves for each category (residential, commercial and industrial) were employed here. In other words, loss calculations were based on damage to specific building use category, and not on individual buildings or on monetary losses caused by reduced functionality. Damage to mobile homes and caravans was not addressed in this study, but can be inferred by evaluating the impacts on standard vehicles. The effects on historical buildings, which was not analysed in this study, should be considered separately, as the replacement costs for their contents and renovations can be higher than for average residential, commercial or industrial buildings.

Residential damage. For the purposes of this study, residential structural values were determined by each neighbourhood's average land price, the number of residential properties recorded in the 2010 Census (GCABA, n.d.), and census meshblocks-weighted floor area, which was based on the ratio of houses to apartments per neighbourhood. Census meshblock is the smallest geographic unit for which statistical data is reported in the national census. Use of weighted floor areas of census meshblocks, plotted as centroids in Figure 13c, did not lead to overestimations of flood damage in relation to the city's footprint (Figure 13a) or raster files (a matrix of cells or pixels; Figure 13b) when compared to published damage data. The city's footprint and raster files probably would have caused overestimations due to the inclusion of non-built areas within property footprints. This is why census centroids were chosen for the quantification of flood damage. Building contents were estimated as 50% of structural value (Nastev & Todorov, 2013). In order to avoid damage values equal to zero, flood depth was reclassified by considering the maximum value of each flood bin (e.g., 0–1 m). This reclassification provided a more conservative approach.

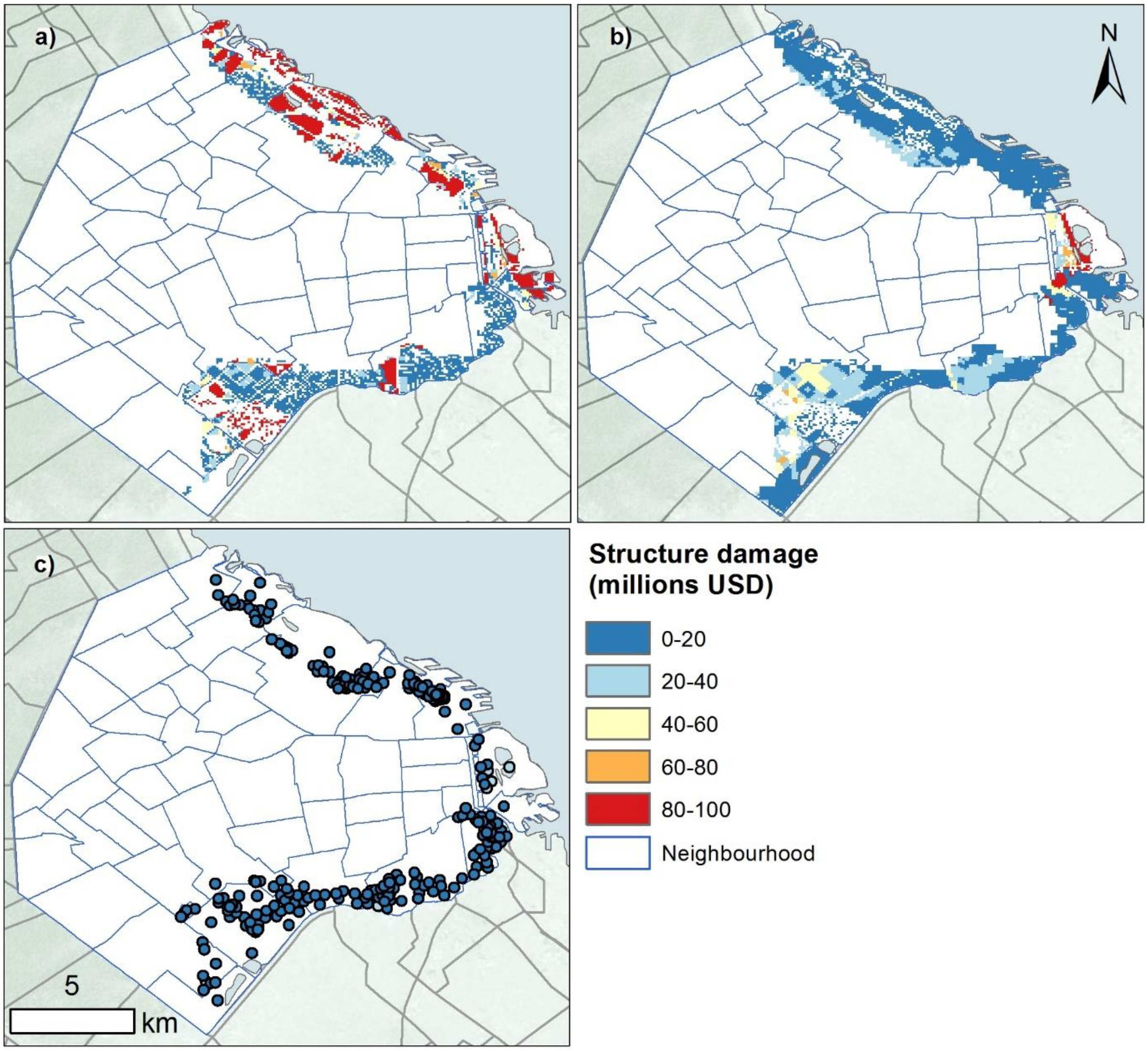

Figure 13. Methodological differences of building damage assessment: a) footprint; b) raster; c) census centroids, the chosen method.

Commercial and industrial damage. The structural values of commercial and industrial buildings were derived from the floor area assigned to each use category, and from neighbourhood land values. Contents values represent 100% and 150% of commercial and industrial building values, respectively (Nastev & Todorov, 2013).

Public infrastructure. For the purposes of this thesis, public infrastructure damage was considered to be a percentage of damage in the residential sector, following the method adopted by the World Bank study (2016). Their results showed that damage to public infrastructure in BA is equal to 4.3% of the damage to residences (World Bank, 2016).

Residential damage reduction. Reductions in structural and contents damage were applied depending on warning lead-time (> or <8 h), following Penning-Rowsell's (2013) method (Table 2). The calculations consider Total potential damage (TPD), as the sum of structure and contents value; Potential inventory damage (PID), which was rounded to 50%, as contents value was assumed to be 50% of structural value (Nastev & Todorov, 2013) in the assessment of residential damage; Moveable inventory damage (MID), as a percentage of potential inventory damage; Reliability and availability (RA), households having received a warning; and Effectiveness (EF), which is the percentage of property at risk saved with warning time.

Table 2

Potential Damage Reduction to Residential Properties, BA (Penning-Rowsell et al., 2013)

Parameter	Description	Parameter value (%)	Calculation
TPD	Total potential damage (structure + contents)	100	N/A
PID	Potential inventory damage (as a % of TPD)	52	N/A
MID	Movable inventory damage (as a % of PID)	41	N/A
RA	Reliability–availability (households having received a warning)	30	N/A
EF	Effectiveness- % of property at risk saved with:		N/A
	<8 h warning -time	56	N/A
	>8 h warning -time	71	N/A
TPD saved by	<8 h warning -time	3.58	TPD * PID * MID * RA *E <8h
	>8 h warning -time	4.54	TPD * PID * MID * RA *E >8h

Commercial and industrial damage reduction. Reduction factors in movable contents damage of non-residential properties were applied following the Penning-Rowsell (2013) method (Table 3).

Table 3

Direct Damage Reduction in Non-residential Movable Inventory, BA

Depth (m)	Movable equipment damage reduction (%)
0	43
1	45
2	43
>3	40
Reliability–availability (RA)	0.30
Effectiveness (EF)	0.52

Note. All calculations were based on receipt of a flood warning lead-time >4 hours. Table adapted from Penning-Rowsell et al. (2013).

The flood loss index. The FLI was calculated for each neighbourhood in BA's flood-prone areas. In these calculations, building damage in the worst-case scenario only (in the year 2070, with a 10-year flood recurrence) was considered. The FLI, was calculated in a similar manner to the flood vulnerability index developed for the State of Illinois, in the U.S. (Remo et al., 2016). The FLI was derived from a loss ratio ($Loss_{ratio}$), which incorporates flood loss and flood exposure of residential, commercial and industrial buildings (Equation 1) (Remo et al., 2016).

$$Loss_{ratio} = Flood_{loss} / Flood_{exposure} \qquad \text{(Equation 1)}$$

Then, a floodplain weighting factor (FP_{wf}) was calculated to account for the ratio of neighbourhood areas (NH_A) to exposed areas (NH_{EA}) (Equation 2).

$$FP_{wf} = NH_A / NH_{EA} \qquad \text{(Equation 2)}$$

Finally, the FP_{wf} was multiplied by the neighbourhood's loss ratio to calculate the weighted flood loss ratio ($Wloss_{Ratio}$) (Equation 3).

$$WLoss_{Ratio} = Loss_{ratio} \times FP_{wf} \qquad \text{(Equation 3)}$$

The $Wloss_{Ratio}$ score was normalised (0.0–1.0), so each neighbourhood flood loss score could be ranked and compared by using Equation 4:

$$NLoss_{Ratio} = LR_i - LR_{min} / LR_{max} - LR_{min}, \qquad \text{(Equation 4),}$$

where LR_i is the $WLoss_{Ratio}$ for each neighbourhood, and LR_{max} and LR_{min} are the minimum and maximum $Wloss_{Ratio}$.

Post flood clean-up. In this study, property clean-up costs were estimated based on average clean-up times reported for previous flood events, and based on the Argentinian minimum hourly labour rate commonly paid for cleaning jobs (ARS 57.50, or approximately NZD 4), which was set in 2016 (Ministry of labor, employment and social security [Ministerio de Trabajo, Empleo y Seguridad Social], 2016). Calculated clean-up costs only accounted for time spent by people off-work in clean-up and drying activities, but not on cleaning products or repairs. Given that clean-up of commercial and industrial buildings might take longer or involve more complex tasks such as changing the electrical system, moving stock and heavy machinery, using a higher cost per hour in the calculations was considered (5% and 15% extra cost for commercial and industrial buildings, respectively). Multiplication factors were applied to account for weather conditions, as it takes longer to dry properties during colder winter months (Penning-Rowsell et al., 2013). Clean-up costs of the affected road network were based on data from a previous study by Reese (2003, as cited in Reese & Ramsay, 2010), which assumes a cost of USD 8.70/m^2 of flooded road. Calculations took into account average road width (6.55 m) in BA (GCABA, n.d.).

Emergency costs. Emergency costs refer to additional expenses incurred by the BA council and voluntary organisations to minimise flood effects on population and infrastructure, such as evacuation, relief, pumping water out of flooded buildings, hiring private contractors and efforts to prevent loss of vehicles and equipment (Pfurtscheller & Schwarze, 2008). Normal operational costs of the city's Undersecretary of Emergencies were not considered. Given that losses are dependent on the study area and flood event characteristics, several studies have reported a range of emergency costs as a percentage of total property losses. Therefore minimum (2.2%), median (4.7%) and maximum (10.7%) values for BA were considered based on emergency costs reported in the literature.

Results

Delimitation of flood-prone areas. In Lecertua´s (2010) worst-case scenario resulting from a 10-year return flood in 2070, we found the total area in BA, likely to be flooded, to be approximately 46 km^2, which represents 22.61% of the city's current area. We found maximum flood depth to be 4 m, 6 m and 7 m in the 1990, 2030 and 2070 scenarios, respectively (Figure 14). The most exposed neighbourhoods, where more than 50% of the land area was exposed to flooding in the 2070 10-year return flood scenario, were Villa Soldati, Puerto Madero, La Boca, Retiro, Villa Riachuelo and Palermo (Figure 15). Slums also fell well within the flood hazard area, especially in the south of the city, highlighting the issue of social vulnerability in those neighbourhoods (Koks, Jongman, Husby, & Botzen, 2015).

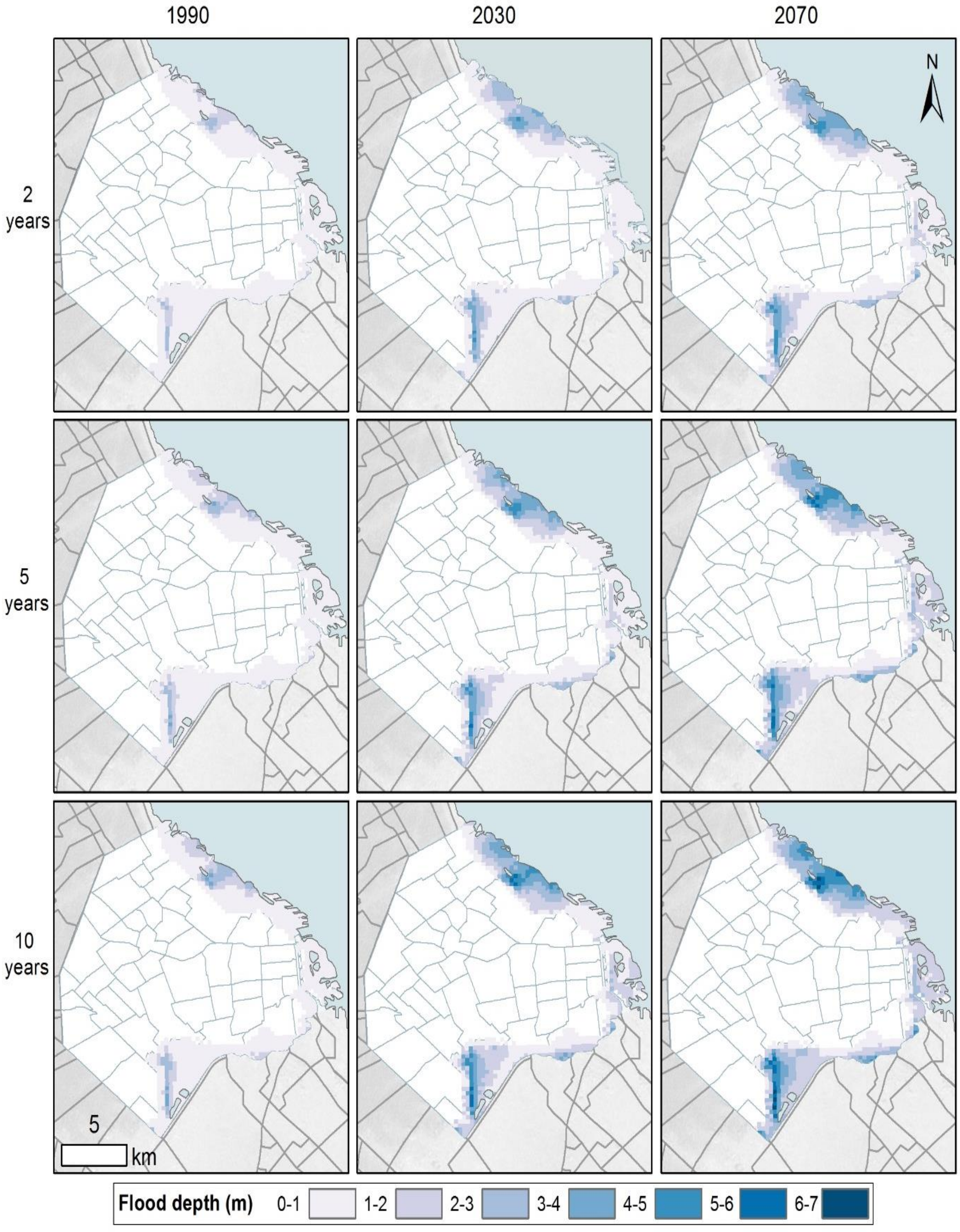

Figure 14. Flood-exposed areas in BA based on various scenarios (for the years 1990, 2030 and 2070) and return periods (2, 5 and 10 years). Maps adapted from Lecertua (2010).

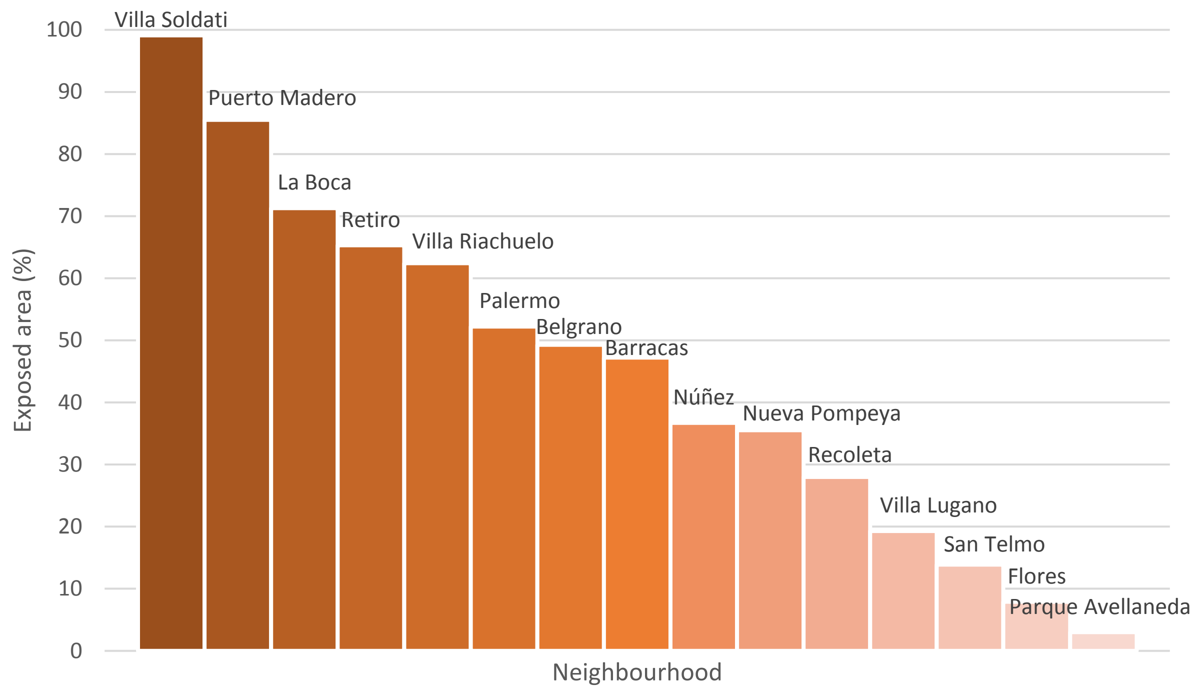

Figure 15. Flood-exposed area (%) per BA neighbourhood to 10-year return flooding in the year 2070.

Damage to infrastructure and utilities. In some neighbourhoods, infrastructure lifelines and utilities are more exposed than in other neighbourhoods, a factor that influences the response and repair phases (Figure 16). Small increases in damage sustained by infrastructure lifelines and utilities could be seen in scenarios where floods recur every 2, 5 and 10 years (Table 4). In other words, damage to infrastructure lifelines and utilities is greater when floods recur every 10 years than 2 years. Therefore, the longer the return period, the higher the flood depth and resulting damages.

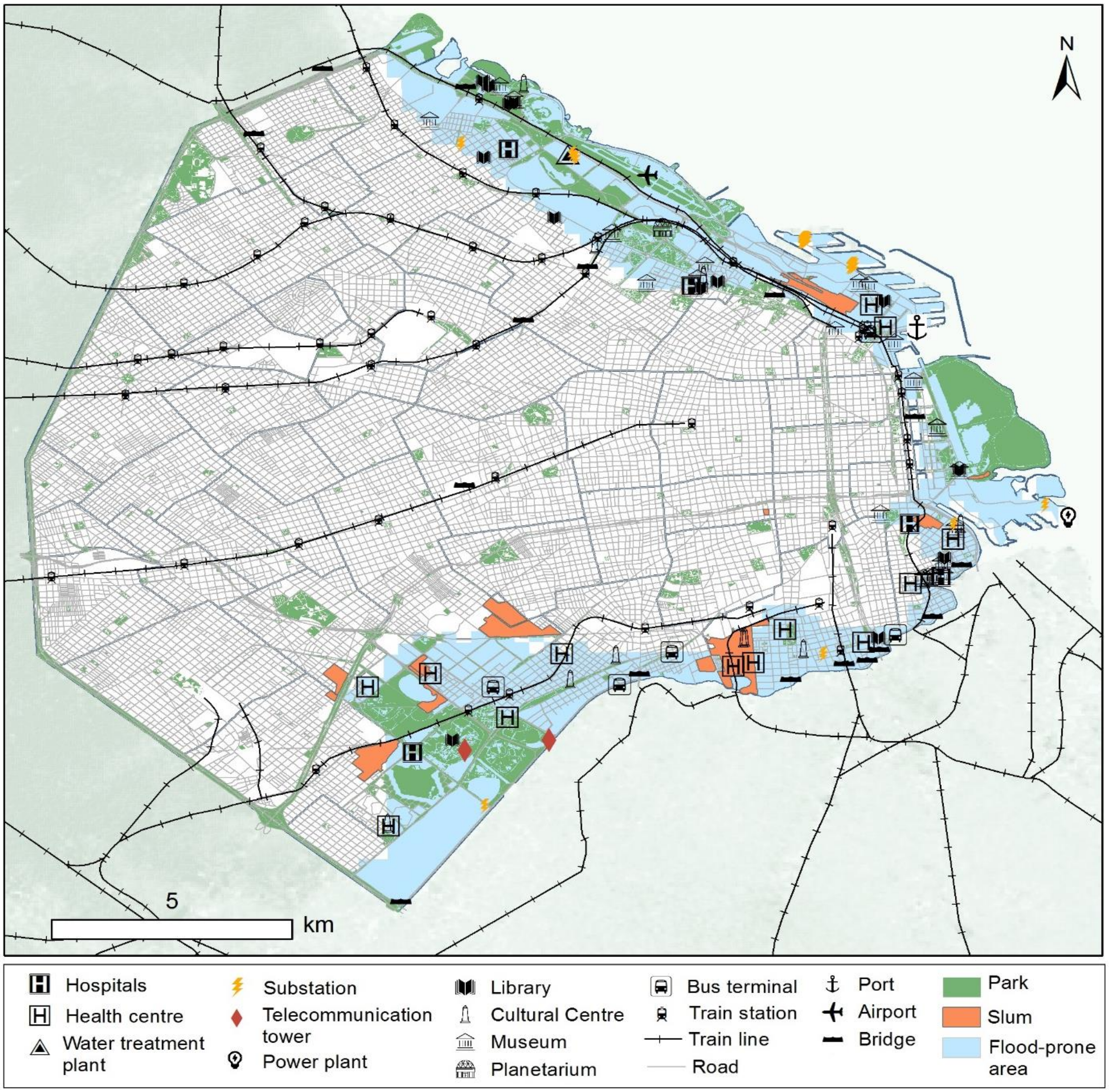

Figure 16. BA infrastructure lifelines and utilities located in areas prone to 10-year return flooding in the year 2070 (GCABA, n.d.).

Small increases in damage sustained by infrastructure lifelines and utilities could be seen in scenarios where floods recur every 2, 5 and 10 years (Table 4). In other words, damage to infrastructure lifelines and utilities is greater when floods recur every 10 years than 2 years. Therefore, the longer the return period, the higher the flood depth and resulting damages.

Table 4.

Damage to infrastructure lifelines and utilities in BA in different flood scenarios

Scenario (year)	Return period (years)	Transport					
		Highways	Bridges	Bus lines	Train lines	Airport	Port
1990	2	2	0	17	2	1	0
	5	2	1	18	2	1	0
	10	2	1	22	2	1	0
2030	2	2	3	36	3	1	0
	5	4	7	54	4	1	0
	10	4	9	62	4	1	0
2070	2	4	7	54	4	1	0
	5	4	10	64	4	1	0
	10	4	10	80	4	1	1

Scenario (year)	Return Period (years)	Energy, water and communication				Health		Culture and environment	
		Substations	Thermal power plant	Water treat-ment plant	Tele-communications towers	Hospitals	Comm-unity health centres	Cultural centres	Parks
1990	2	0	1	1	0	5	13	0	19
	5	3	1	1	0	5	13	1	25
	10	5	1	1	0	5	13	1	29
2030	2	4	1	1	1	5	13	8	48
	5	5	1	1	1	5	13	12	70
	10	26	1	1	1	5	13	12	83
2070	2	5	1	1	1	5	13	12	72
	5	38	1	1	2	5	13	19	88
	10	38	1	1	2	5	13	22	100

The water treatment plant. The BA water treatment plant General San Martín, on the northeast side of the city, lies in the flood-prone area, and could be impacted by 1–4 m of flood water, with waves and debris, damage to its pipes, machinery and electrical components and disruption of the treatment process. Flood duration affecting the plant ranged from 1 h in the baseline 1990 scenario to 4 h in the year 2070, without considering repair time. In these scenarios, not only the BA population, but also the whole metropolitan area, might be left without potable water. The water intakes in the La Plata River are already vulnerable to tidal influences and southerly winds that cause river level to rise in normal weather and tidal conditions (GCABA, 2010).

Waste water is discharged into the La Plata River after being treated outside the city on the coast of the Berazategui District, which is also exposed to floods. Results indicated that disruption to the waste water treatment plant might require retaining effluent until the plant's storage capacity is reached; installing temporary storage facilities; or diverting effluent to operable facilities located in the north and west of the city. The latter option seems like a very difficult and unlikely prospect.

The thermal power plant. From the scenarios generated for this study, it appeared that because of its location on the southeastern coast of BA, the Costanera thermal power plant (1,800 MW capacity), the only one in the city, may be exposed to 1 m floods lasting from 1–2 h. It provides power to part of the city and approximately 7% to the national power grid (National Board of Electricity [Enel] , n.d.). Power outages are a major issue during a normal summer in BA, as the electricity network is not extensive enough to cope with BA's rapid population growth. This situation can be worsened by southerly winds, which are recurrent during the summer season, and which cause floods that may affect the thermal power plant. Fuel tanks located at the power plant could be a potential source of contamination if they are damaged by floods.

Substations and telecommunications towers. Flood-affected populations within 1 km of substations located in BA's flood-prone area number approximately 873,884 city inhabitants in total (16% of the total population). Estimates were even higher when considering populations within a 1 km radius of substations outside the city boundaries. To combat power outages, mobile substations and generators would be necessary, especially in hospitals, in retirement villages where people are dependent on electricity to stay alive, and at emergency management facilities where vital communications depend on the power supply (fire brigades, police stations, civil defence headquarters and the city's Emergency Coordination and Control Centre [CUCC]). At the moment, the General Directorate of Logistics and Civil Defence are able to provide 23 generators of different capacities to assist vulnerable populations and governmental agencies (Buenos Aires Civil Defence, 2016; General Directorate of Logistics [Dirección General de Logistica], 2016). Also, a VHF radio system and alternative batteries are available to BA emergency managers to guarantee communication during emergencies.

Furthermore, if telecommunications towers in the hazard area were damaged, the number of affected people within a 1 km radius of the towers would number 11,231 city inhabitants (6% of total BA population). The scenarios generated indicated that larger impacts can be expected if visitors or workers within the coverage area are taken into account. Interruptions in the telecommunications network can hinder the issuance of flood warnings to the population, and can thwart emergency response efforts. Temporary transmitter towers, satellite entrance links, or mobile microwave repeaters will be necessary to lessen the impacts, recently acquired by the city council (J. Granvillano, Emergency Coordination and Control Centre, personal communication, 10th January, 2017). In the scenarios generated by this project, telecommunications towers could be affected by floods of up to 2 hours, and substations could be hit by floods lasting a maximum of 4 hours. However, these calculations did not include the time needed to restore telecommunications services, suggesting more lengthy outages would be likely.

Hospitals and health centres. Five hospitals and 13 health centres in the BA metropolitan area are likely to be affected by riverine floods. Results showed that these health facilities could be affected from ground level up to 3 m in the 2070 scenarios. People living within 1 km of these facilities amounted to 8% of the total city population. Calculations also indicated 13% of the total population in BA lives within 1 km of community health centres in the flood-prone hazard area, and they might not be able to use the facilities when floods restrict access. Staff working in flood-prone areas, and people from suburban areas who use the city's healthcare facilities, could also be included in impact assessments, making for higher impacts.

If health centres and hospitals are shut down, or if their services are limited during floods, patients will need to travel longer distances to reach other centres. Consequently, facilities receiving patients from flooded areas will probably be overcrowded. In this case, more resources and staff will be necessary to respond to the greater demand. In addition, power outages or loss of equipment and medical resources should also be considered in flood scenarios. Current project results showed that hospitals and health centres could be affected by floods lasting a maximum of 3 h in the year 2070–10-year return flood scenario.

Transport disruption. Access to the city can be limited due to direct impacts or debris blocking roads, highways, highway ramps and bridges. Our results showed that access in the east of BA will be limited, as Ramon Castillo and Del Libertador Avenue highway ramps will be exposed to floods, which will make access to Highway Illia difficult. Highway Illia connects eastern areas of BA to the northern and south-eastern areas of the city. In addition, current projections suggested that commuters from BA’s southern metropolitan areas will struggle to access the city during floods, as Highway Campora in the south-west, and Highway Frondizi and the BA–La Plata Road in the south-east will be affected by floods, as they were in 2013 (UNLP, 2013). Highway Illia and Campora will be affected in all scenarios, while Frondizi and BA–La Plata will only be affected in future scenarios (in the years 2030 and 2070). Furthermore, impacts on bridges or their access ramps may also hinder traffic flows in and out of the city, especially in future flood scenarios. Bridges thus affected included La Noria, Bosch, E. Demonty, Pueyrredon, Nuevo Pueyrredon, Victorino de la Plaza, Avellaneda, Barraca Peña in the south, and Figueroa Alcorta and Labruna in the east.

The connection of BA with other metropolitan areas is very important, because there are more than 2 million commuters who enter to the city daily to work and study (World Bank, 2016). Product and service supply chains can be adversely affected as well, because industrial complexes are mainly located on the outskirts of the city.

Transport disruption can also be measured by total affected passengers, average ticket value and flood duration. Results indicated that flood scenarios and recurrence periods are directly related to transport disruption as flood duration increases. Also, impacts can last longer than flood duration as extra time might be necessary to repair damaged infrastructure and to restore transport services. More details about disruption to different means of transport are explained in the following sections.

City buses. Results indicated that, in total, 80 bus lines could experience delays or disruption as they traverse inundated areas that could be flooded a minimum of 3 hours (as in the 1990–2-year return flood scenario), or a maximum of 7 hours (as in the future year 2070–10-year return flood scenario). A minimum loss of USD 26,500 (based on 2017 fares) could be expected in the baseline scenario of a 2-year recurrence, where maximum flood duration is 2 hours (Figure 17). Approximately 69,300 passengers (2% of the BA population) would be delayed or left without the means to return home. The worst-case scenario proved to be the year 2070–10-year recurrence flood, where flood duration could scale up to 7 hours. In this scenario, using local statistics (Buenos Aires Ciudad, 2016) of hourly passengers per bus line and ticket value, we found that 761,200 passengers (26% of the 2010 BA population) could be affected, and around USD 291,000 could be lost.

Train lines. According to scenario results, the BA train lines that will be exposed to inundation in the future are General Mitre, Belgrano (North and South), San Martin and Roca. The baseline scenario (for the year 1990), regardless of the recurrence period, generated minimum losses of USD 5,800 to train lines, and affected a total of 24,900 passengers (0.8% of the BA population), with a worst-case flood duration of 3 hours. Similar to bus route disruption results, the future year 2070–10-year recurrence scenario caused the most impacts. In the future, train lines can be expected to be exposed to 6 hours of inundation that will affect 118,600 passengers (4% of the 2010 BA population), which will incur a USD 27,900 loss (Figure 17).

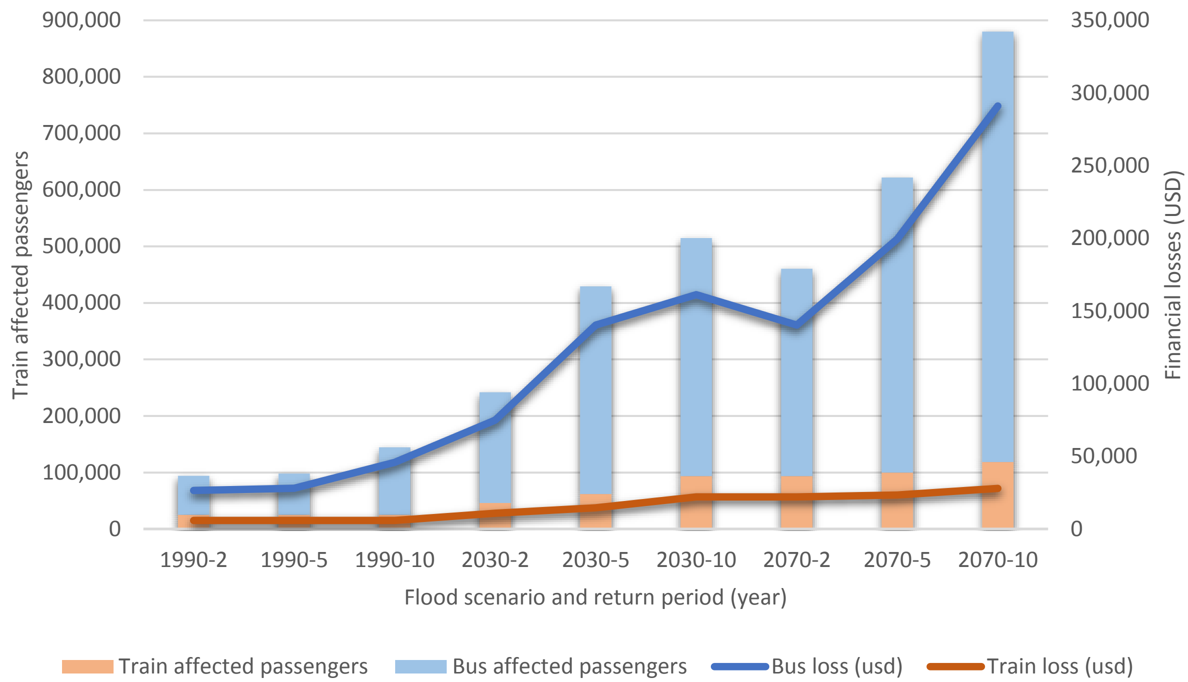

Figure 17. Affected passengers and financial loss due to transport disruption based on passengers per number of affected lines and 2017 ticket value.

Note. Flood scenarios (1990, 2030 and 2070) and return periods (2, 5, 10 years) in the graph are separated with a dash (e.g. scenario 1990 – 2 year return flood).

The airport and port. Inundations at Jorge Newbery Airport could affect domestic and international flights to neighbouring countries, and the scenarios generated indicated passengers may be delayed from 2 hours or 5 hours in the 1990–2-year recurrence, and in the future year 2070–10-year recurrence scenarios, respectively. This flood scenario calculation showed that a minimum of 536, or a maximum of 1,339 passengers (either arriving or departing), would be delayed, based on local statistics of passengers passing through this airport (Buenos Aires Ciudad, 2016).

The BA port could be exposed to 1 m flood waters for 1 hour only in the year 2070–10-year recurrence flood scenario, which would hamper an estimated 305 passengers and 738 shipping containers. Further, in comparison to other means of transport, disruption at the airport and port should affect the least number of people. However, economic losses may be greater, as ticket values for flights and infrastructure investments at the port and airport are higher than for other means of transport.

Cultural activities and the environment. Scenarios indicated that the highly active cultural life of BA and tourism could easily be disrupted by future floods. Popular museums, libraries, cultural centres and the “Galileo Galilei” Planetarium lie in the flood-prone area. Damage to them could exceed average impacts on other types of buildings, because the cost of renovations might be higher, and replacement of historical content may be more difficult. Even if such special buildings and their contents were not flooded, access to them might become limited. The loss of entertainment opportunities might further reduce the quality of life for flood victims and people outside the hazard area (Penning-Rowsell et al., 2005). In addition, mapping indicated that approximately 5 km^2 of parks, including Costanera, the only nature reserve in the city, are located in the hazard area, which if flooded, would constrain recreational opportunities and conservation efforts.

In addition, potential fire and contamination of soils, surface and groundwater can be expected if fuel tanks and the pipe system connected to them are severely scoured by flood waves and debris. Controlling and extinguishing a fire, or immediate remediation, might be further complicated if the road network is fully inundated. Damage to the city’s 47 fuel tanks may cause a petrol supply shortage needed for alternative transport or mobile generators in case of power outages. Neighbourhoods exposed to fire and contamination include Palermo, Retiro in the east and La Boca to the south; however, impacts could extend to other areas if flood waters transport contaminants. In addition, the city’s 916 transformers, which were mapped here, are spread throughout the flood-prone area, and they are also a source of contamination, because they contain polychlorinated biphenyl (PCB), a bioaccumulative substance. There is no information publicly available about the height at which transformers are mounted, so it is difficult to establish their level of exposure to flood waters.

Economic losses.

Vehicle damage. 32,447 vehicles were estimated to exist in BA's flood-prone area, with 897 cars entering the city daily (Buenos Aires Ciudad, 2016) amount to a total of 33,344 flood-vulnerable cars (Table 5). During working hours, 25% of the total number of cars is assumed to be on the road, which results indicated represents a minimum loss of USD 18 million and a maximum loss of USD 74 million in a 0.3 m or a 0.6 m flood, respectively. Damage to vehicles during non-working hours could be higher, because 90% of vehicles are assumed to be on the road when people are not working. In the case of a 0.3 m flood, USD 66 million could be lost, or USD 266 million in the case of a 0.6 m flood. People have more chance of being affected by floods while commuting to and from their workplace than when driving to any other venue, as work-related travel generates 66.6% of all trips (Transport Secretariat [Secretaría de Transporte], 2007), in comparison to other trips that represent less than 10% of total ground travel time.

Table 5

Vehicle damage in BA based on 2016 values (ACARA, 2017) in different 2070 flood scenarios

			Lost value of vehicles on the road (millions USD)	
Scenario	% of cars on the road	Number of vehicles on the road	0.3 m flood	>0.6 m flood
Working hours	25	8,336	18	74
Non-working hours	90	30,009	66	266

Note. Vehicle damage calculations were based on average number of vehicles per household (Ministerio de Transporte, 2009) in flood-prone areas; percentage of cars on the road (Bewsher Consulting Pty Ltd, 2009); 2016 vehicles value (ACARA, 2017); and flood depth damage (Pfluegner, 2001, as cited in Reese & Ramsay, 2010).

***Property and contents damage*.**

Residential damage. Total residential building-related flood losses were estimated to be USD 8,000 million (derived via HAZUS), or USD 6,800 (derived via MERK), in the less severe scenario (a year 1990–2-year recurrence); and USD 10,500 million (HAZUS), or USD 9,400 million (MERK), in the worst-case scenario (a year 2070–10-year recurrence) (Table 6 and Figure 18). Damage to residential housing increases as expected, with incrementally worsening flood scenarios and with increasingly long return periods. Damage was worse in acute scenarios due to higher flood depths.

The largest scenario-based flood losses were concentrated in the neighbourhoods of Palermo, Barracas, Villa Soldati, La Boca, Puerto Madero, Retiro and Villa Lugano for all flood scenarios. Mapping work revealed pockets, or small groups of census centroids, with higher building damage potential than surrounding cells, a variance mainly caused by higher population density. For instance, despite the low structural and contents values of slum buildings, calculations indicated damage could be relatively high in comparison to surrounding census centroids because of the high housing density, as shown in the Figure 18a inset depicting damage values to slums in the Barracas neighbourhood. This was in direct contrast to Puerto Madero, where results indicated higher building damage values per census centroid. Figures were influenced by higher land prices, as shown in Figure 18d.

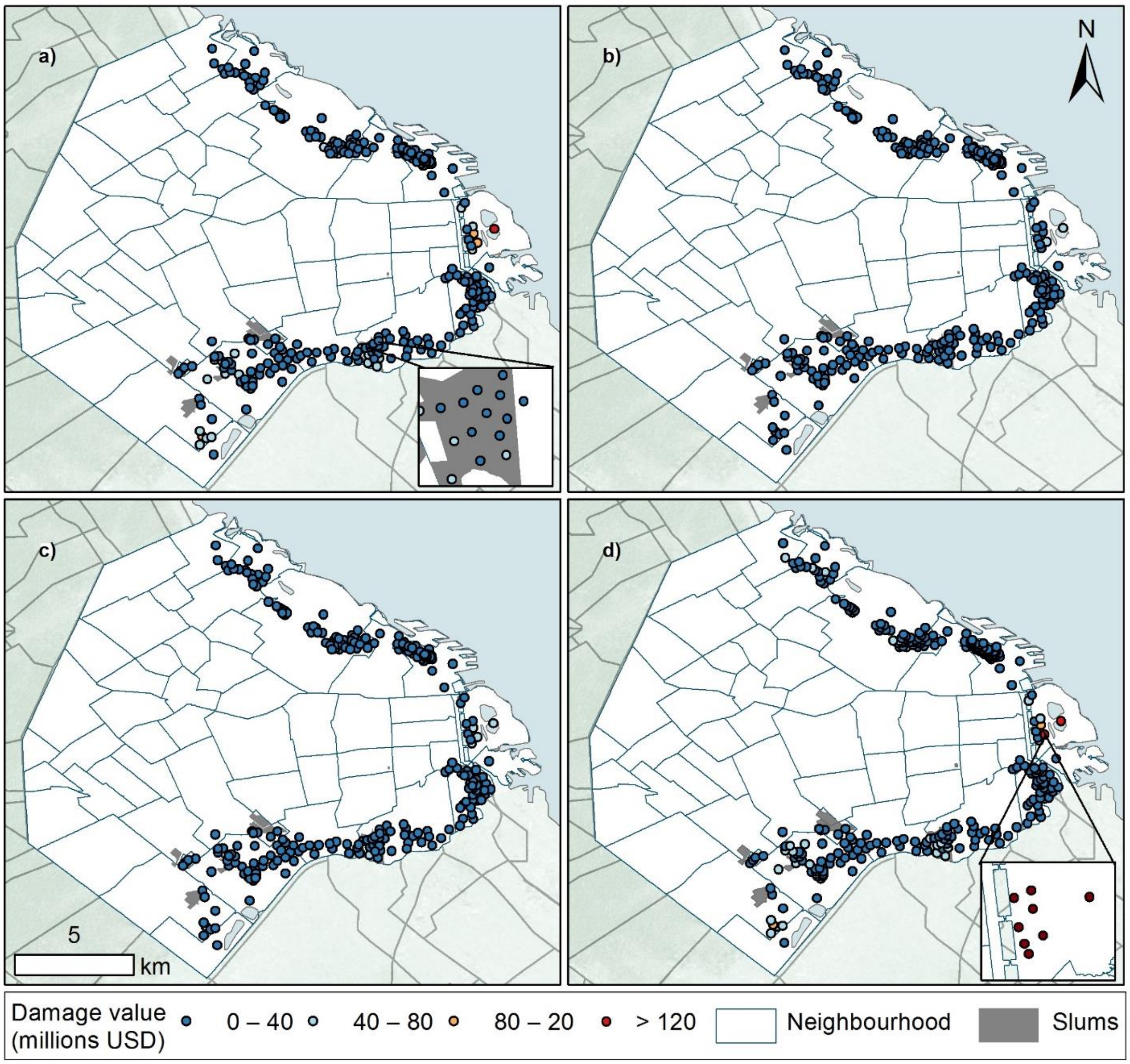

Figure 18. Residential damage in the worst-case scenario (a year 2070–10-year flood event). Structural losses as estimated by: a) HAZUS method; and b) MERK method. Contents losses as estimated by: c) HAZUS method; and d) MERK method.

Commercial damage. Commercial building and contents losses were directly related to the flood scenario and return period. Aggregated commercial losses ranged from a minimum of USD 36,400 million (via HAZUS method), or USD 35,700 million (via MERK method), in the year 1990–2-year recurrence flood scenario. Losses went up to USD 50,000 million (HAZUS), or USD 47,500 million (MERK), in the future year 2070–10-year recurrence scenario (Figure 19 and Table 6). The most affected commercial businesses in all scenarios were garages, storehouses, food and beverage retailers (including markets and restaurants), clothing stores and vehicle workshops.

Analyses of flood losses per census block showed that the greatest future flood impacts will probably be concentrated in the Belgrano, Palermo, Villa Soldati, Barracas and Nuñez neighbourhoods in all flood scenarios. In this research, commercial building density was a paramount factor predicating commercial damage, especially in Belgrano (which has 1,000 stores per km^2 based on BA city council georeferenced data (GCABA, n.d)). Because land price is very high in Palermo, Belgrano and Nuñez (>USD 2,800 m^2), scenarios showed losses sustained in these neighbourhoods to be correspondingly high. Floor area also exerted a significant influence on large properties like supermarkets, garages, sports fields and transport terminals.

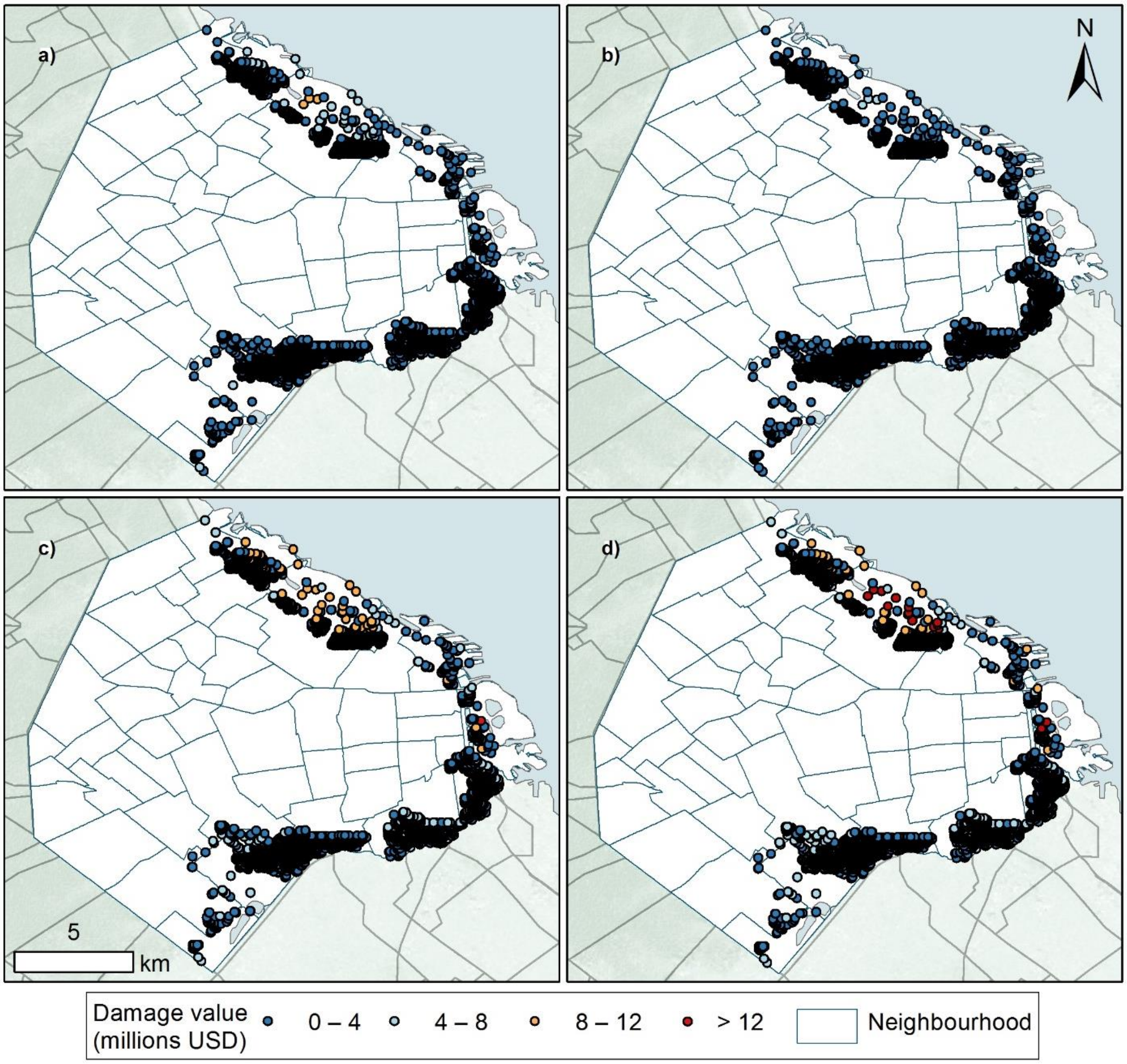

Figure 19. Commercial damage in the worst-case scenario (a year 2070–10-year flood event). Structural losses estimated by: a) HAZUS method; and b) MERK method. Contents losses estimated by: c) HAZUS method; and d) MERK method.

Industrial damage. Total industrial building-related flood losses in the city of BA could reach USD 320 million (via HAZUS estimation method), or USD 174 million (via MERK method), in the less severe scenario (a year 1990–2-year recurrence); and USD 468 million (HAZUS), or USD 322 million (MERK), in the worst-case scenario (a future year 2070–10-year recurrence) (Figure 20 and Table 6). Analysis also showed that higher impacts might be expected in future scenarios (in the years 2030 and 2070), when sea levels and flood depths may rise due to climate change. Effects on industries were smaller in comparison to residential and commercial properties, because industrial endeavours are not currently the main economic earner in the city of BA. In the industrial building category, the most affected buildings were sheds, carpentries and pharmaceutical factories.

Furthermore, flood impacts to industrial buildings and their contents may affect Belgrano, Recoleta, Retiro, Palermo, Barracas, Villa Soldati, La Boca, Nueva Pompeya and San Telmo industrial complexes, where building clusters are most concentrated. Despite low land prices in the south of BA, results showed that the largest flood losses were concentrated in southern neighbourhoods (Barracas, Villa Soldati, La Boca and Nueva Pompeya), because the affected industrial land area is larger than in the north, where land prices are higher but total land area is significantly smaller.

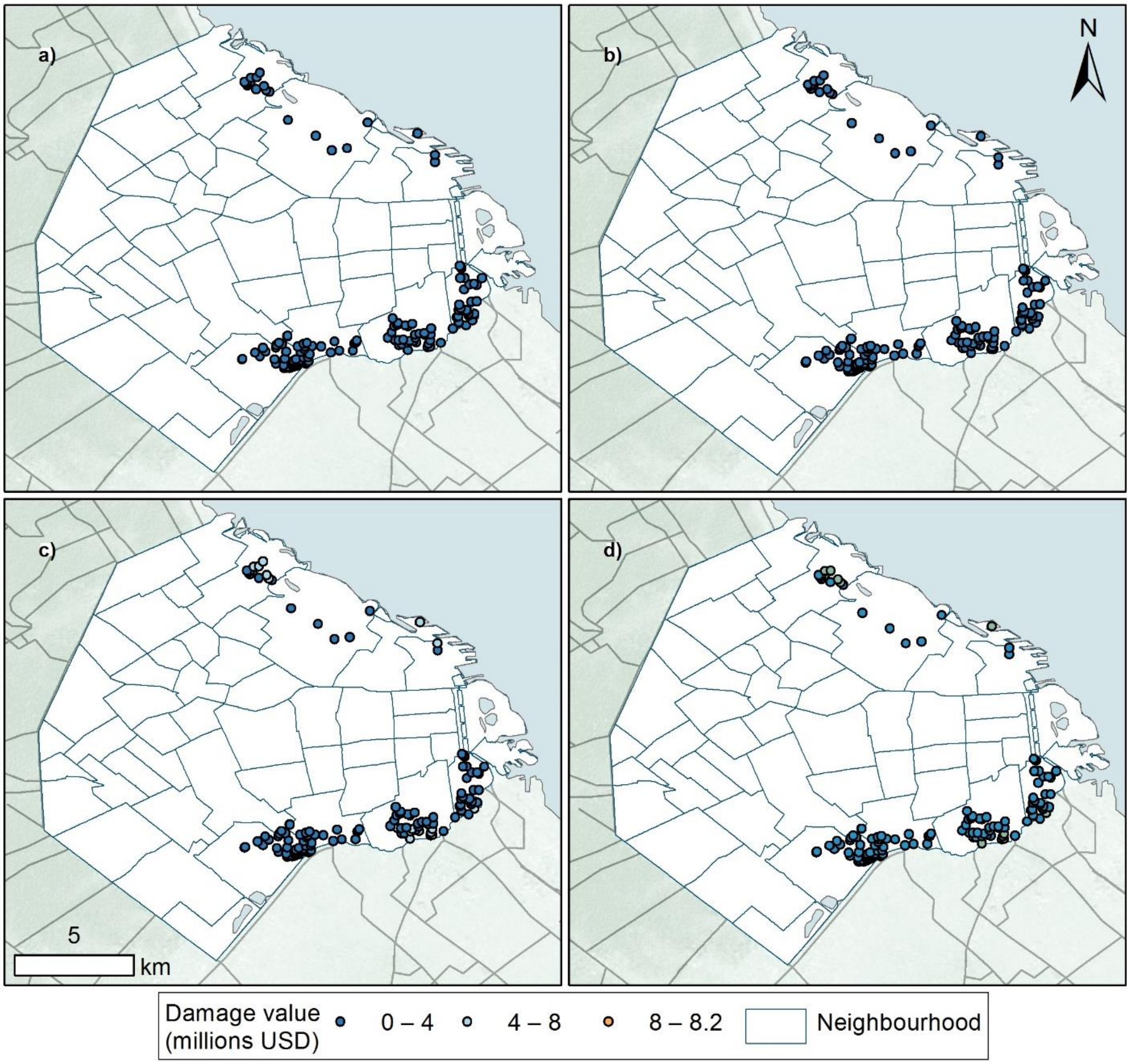

Figure 20. Industrial damage in the worst-case scenario (a year 2070–10-year flood event). Structural losses estimated by: a) HAZUS method; and b) MERK method. Content losses estimated by: c) HAZUS method; and d) MERK method.

Table 6

Residential, Commercial and Industrial Building and Contents Damage

Residential									
		Building structures			Contents			Reduced total damage with flood warnings in place	
Scenario (year)	Return period (years)	HAZUS	MERK	HAZUS–MERK % difference	HAZUS	MERK	HAZUS–MERK % difference	HAZUS	MERK
1990	2	5,067	1,454	111	2,986	5,432	-58	7,125	5,958
	5	5,117	1,479	110	3,016	5,487	-58	7,204	6,037
	10	5,134	1,487	110	3,026	5,506	-58	7,231	6,064
2030	2	5,329	1,592	108	3,144	5,717	-58	7,544	6,380
	5	5,763	1,810	104	3,403	6,195	-58	8,237	7,075
	10	6,058	1,962	102	3,578	6,517	-58	8,707	7,550
2070	2	5,802	1,829	104	3,426	6,238	-58	8,299	7,138
	5	6,218	2,063	100	3,678	6,686	-58	8,967	7,820
	10	6,626	2,300	97	3,923	7,123	-58	9,620	8,494

Commercial									
		Building structures			Contents			Reduced total damage with flood warnings in place	
Scenario (year)	Return period (years)	HAZUS	MERK	HAZUS–MERK % difference	HAZUS	MERK	HAZUS–MERK % difference	HAZUS	MERK
1990	2	7,424	4,086	58	29,025	31,620	-9	34,985	34,242
	5	7,450	4,098	58	29,070	31,667	-9	35,056	34,300
	10	7,469	4,106	58	29,104	31,702	-9	35,109	34,344
2030	2	8,113	4,382	60	30,300	32,947	-8	36,955	35,872
	5	9,531	4,987	63	32,767	35,547	-8	40,857	39,093
	10	10,582	5,437	64	34,716	37,584	-8	43,869	41,593
2070	2	9,670	5,045	63	32,976	35,777	-8	41,207	39,383
	5	11,546	5,836	66	35,818	38,889	-8	45,950	43,309
	10	12,674	6,311	67	37,328	40,516	-8	48,600	45,425

Industrial									
		Building structures			Contents			Reduced total damage with flood warnings in place	
Scenario (year)	Return period (years)	HAZUS	MERK	HAZUS–MERK % difference	HAZUS	MERK	HAZUS–MERK % difference	HAZUS	MERK
1990	2	79.2	36.7	73.4	241.0	137.9	54.4	306	160
	5	79.3	36.7	73.4	241.1	138.1	54.4	306	160
	10	79.3	36.7	73.4	241.1	138.1	54.4	306	160
2030	2	82.2	37.9	73.8	247.0	145.2	51.9	315	169
	5	97.5	44.2	75.3	278.6	183.1	41.4	362	213
	10	102.3	46.1	75.7	288.6	194.6	38.9	377	227
2070	2	97.6	44.2	75.3	278.6	183.2	41.3	362	213
	5	119.4	53.4	76.4	320.9	238.3	29.6	426	278
	10	129.3	57.8	76.5	338.9	264.5	24.7	454	309

Note. All figures are shown in millions of US dollars (USD). Damage figures other than those presented in the last 2 columns are for scenarios where no flood warnings were given. Warning times for residential buildings are assumed to be <8 h, and for commercial and industrial buildings, warning times are assumed to be >4 h (Penning-Rowsell et al., 2013).

The flood loss index. The FLI (0 = low; 1 = high structure and contents loss) derived from both HAZUS and MERK calculations revealed that Parque Avellaneda was likely to be the most flood-affected neighbourhood, followed by Flores, San Telmo, Villa Lugano and finally, Recoleta. The floodplain weighting factor (FP_{wf}) had a considerable influence in Parque Avellaneda, Flores and San Telmo, while the loss ratio ($Loss_{ratio}$) was more important in calculations for Parque Avellaneda, Recoleta and Villa Lugano (Figure 21).

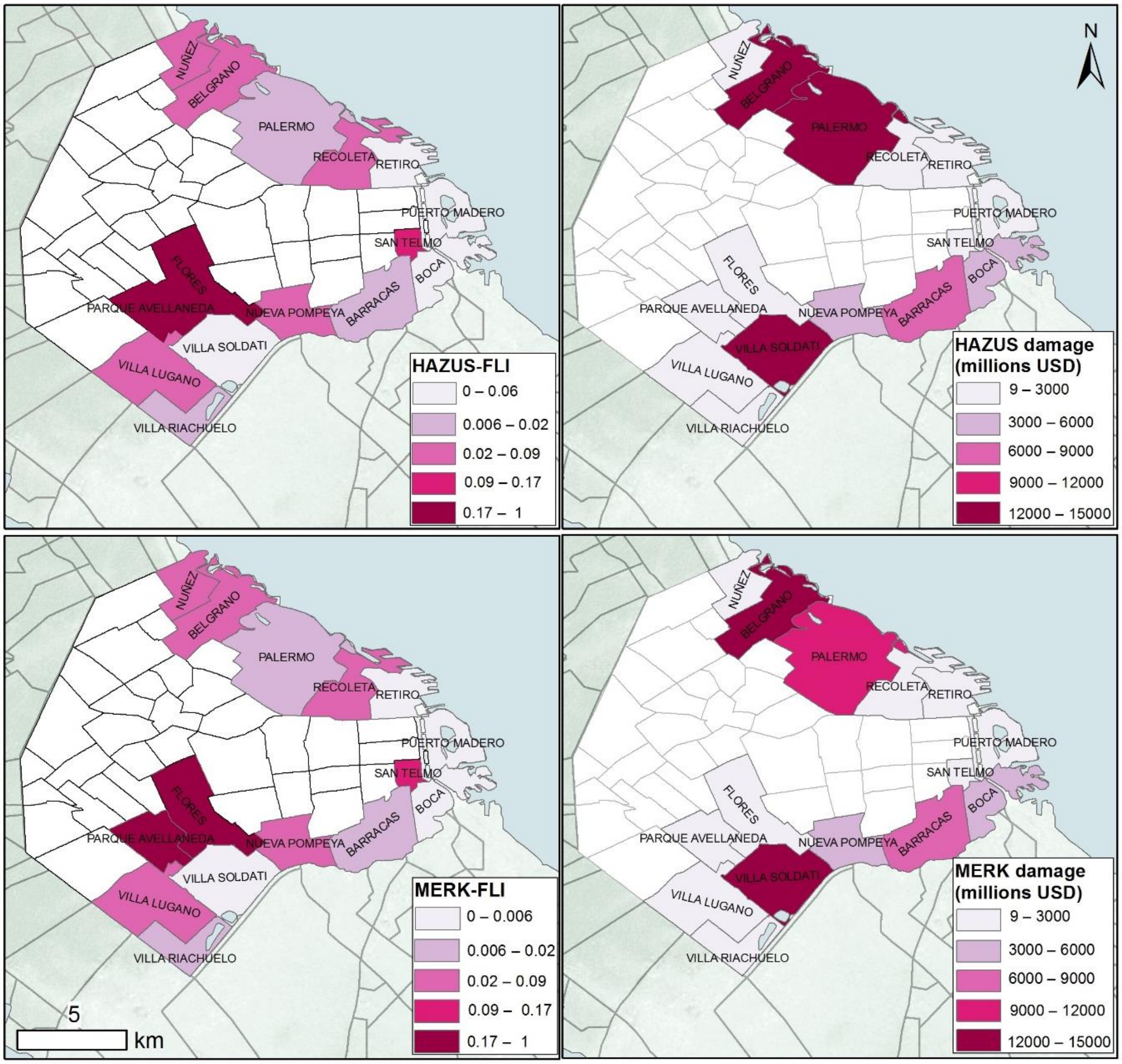

Figure 21. Flood loss index (FLI) compared to total building damage in the worst-case scenario (the future year 2070–10-year return flood) derived from HAZUS (Karamouz, Fereshtehpour, Ahmadvand, & Zahmatkesh, 2016) and MERK (Markau, 2003 as cited in Sterr et al., 2005) damage assessment methods.

Damage reduction. Residential potential damage costs with less than 8 hours flood warning time, which amounted to USD 900 million according to calculations (Table 6) represented, on average, 20% less savings in comparison to damage costs incurred after receiving a warning more than 8 hours prior to a flood event in the 2070-10 year flood scenario. With more than 8 hours' warning time, scenarios yielded a USD 1,100 million saving, as per the Penning-Rowsell et al. (2013) reduction factor. In all scenarios, savings on damage costs to commercial assets with a warning time of more than 4 hours oscillated around USD 1.4 billion. This represented an average of 2.8% savings on the total value of commercial contents in the flood-prone area of BA. With a warning time of 4 hours, savings realised for damage to industrial sites hovered around USD 14 million, which represented 2.1% of the value of industrial equipment.

Damage to public infrastructure. Damage to public infrastructure was a mere 4.3% of the damage sustained by residential buildings. Losses ranged from a minimum of USD 346 million (according to HAZUS calculations), or USD 296 million (according to the MERK method), in the 1990–2-year recurrence scenario; and up to USD 453 million (HAZUS), or USD 405 million (MERK), in the future year 2070–10-year recurrence scenario.

Post flood clean-up. Residential property clean-up accounts for higher costs as more residences are exposed, in contrast to commercial businesses and industries. Total cleaning expenses for residential, commercial and industrial buildings represented around USD 4 million, if an average clean-up of 14 h was used to calculate costs. The average clean-up time of 14 h was used, because this figure has been reported as the average time required after floods in La Plata, Argentina ("Almost 50 deaths," 2013) (Table 7). These values increased by 157% for 36 hours of cleaning, a figure reported as the average clean-up time required after hurricane Katrina in New Orleans, in the U.S. (Riggs et al., 2008). Calculations showed a 1957% increase in clean-up costs if 12 days (approximately 288 hours) were required, as registered after three flood events in New Zealand (Reese & Ramsay, 2010). Factors of 2 and 5 were applied to total clean-up values to account for weather conditions during autumn and winter, respectively, as it takes longer to dry properties and chattels during colder months. Furthermore, calculations showed that road clean-up could add up to USD 25 million in BA, as 451 km of the road network lies within the flood-prone area.

Table 7

Post flood clean-up costs in BA based on building use category and cleaning hours

Building type	Minimum (14 hours)	Moderate (36 hours)	Maximum (288 hours)
Residential	4,245,333	10,916,571	87,332,569
Commercial	517,194	1,329,926	10,639,410
Industrial	7,733	19,884	159,073
Total	4,770,274	12,266,418	98,131,341
Multiplication factor			
2 (Autumn)	9,540,547	24,532,835	196,262,682
5 (Winter)	23,851,368	61,332,088	490,656,706

Note. All figures are reported in US dollars (USD).

Emergency response costs. Emergency response costs for BA in the least severe scenario (the year 1990–2-year return flood) could range from USD 986–USD 4.796 million, while in the worst-case scenario (the future year 2070–10-year return flood), emergency response costs could vary from USD 1,342–USD 6,527 million (Table 8).

Table 8

Emergency response costs

Scenario (year)	Return period (years)	Emergency response costs (millions USD)		
		Minimum	Medium	Maximum
1990	2	986	2,107	4,796
2070	10	1,342	2,867	6,527

Discussion

Flood losses estimated for the purposes of this study varied according to flood return period and scenario, land use, damage evaluation method, FLI, damage reduction factors, additional costs and economic factors. Details about these variations are presented in the following sections.

Flood scenarios. Small increases in building damage between return periods (of 2, 5 and 10 years), due to higher flood waters commonly experienced with longer return periods, were evident. Increments of variation between return periods were larger in the 2030 and 2070 scenarios than in the baseline (the 1990 scenario). Furthermore, losses were compounded in future flood scenarios (the year 2030 and 2070 calculations). For example, total building damage rose by 23% from the 1990 to the 2030–10-year flood return scenarios. The larger increases between flood scenarios highlighted the influence of climate change-driven sea level rises predicted for BA in the future. Flood depths, sea level rises, the characteristics of flood-exposed areas, and other factors such as land price and housing density, predicated structural and contents losses. These factors also drove the differences we observed in damage costs to different BA neighbourhoods.

Land use. Flood damage to commercial business premises and their contents represented the greatest losses in the city, regardless of the damage evaluation method or flood scenario. The effects on businesses exceeded those on residential properties, even though the number of houses is 159% higher in BA. This discrepancy shows the weight that commercial contents (100% of structural value) play in calculations. Contents damage to non-residential buildings was far greater than structural losses because of high contents value. This result relates to the fact that structural components tend to resist flooding, while non-structural components and contents are more perishable (Scawthorn et al., 2006).

The differences between damage sustained by commercial and industrial buildings are governed not only by the number of properties in the flood area and their floor area, but also by land value. The number of industrial premises located in BA's flood-prone area is significantly smaller — by approximately 200% — than the number of commercial buildings in the same area. Furthermore, industries are mainly located in southern BA, where land is cheaper, while commercial businesses are widely dispersed across neighbourhoods.

Regarding public infrastructure, the fact that many governmental offices are in the city centre (the Recoleta, Retiro and San Telmo districts), well inside the flood-prone area, implies that many administrative and managerial activities will be interrupted during a flood, which might affect emergency response efforts. Furthermore, the dedicated CUCC lies in the Chacarita neighbourhood, which is located 400 m from areas that have been identified by the city council as prone to waterlogging, which might limit access by hazard managers and local authorities to the centre.

Results clearly showed that the floods BA is likely to sustain will also affect infrastructure lifelines and utilities. The magnitude of the damage and indirect effects depend mainly on flood depth, the duration of disruption and the availability of alternative sources of supplies. This conclusion was also arrived at by Scawthorn et al. (2006). The fact that the General Directorate of Logistics and Civil Defence is able to provide only 23 generators shows the lack of equipment and degree of vulnerability of BA population. In addition, BA residents' degree of dependence on other unaffected lifelines impacted disruption.

Based on these results, it can be concluded the timely, efficient management of information concerning flood risk areas and damage to buildings or infrastructural is critical to managing floods in BA. Information regarding flood risk can inform land use planning, because activities with low damage potential can be allocated to flood-prone areas such as car parks, natural reserves and recreational areas (Messner et al., 2006). To this end, the integration of flood damage and land use databases would be beneficial for informing building consent approvals, and also for property buyers wishing to make the right decisions. In France, flood risk information can be found in a publicly available home information pack (known as the "Dossier de Diagnostics Immobiliers"), and in that country, property vendors and landlords are required to inform purchasers or tenants of potential flood risk to enable them to make more informed decisions ("Flood Risk Areas in France," 2015). Caution is required in implementing such a system, however, as this information made publicly available can influence market values of properties, and insurance premiums (Fedeski & Gwilliam, 2007).

Damage evaluation methods. Damage evaluation methods, such as MERK and its alternative HAZUS, are based on the same concept: depth–damage curves, combined with land use GIS data describing coastal urban areas (Karamouz et al., 2016; Markau, 2003 as cited in Sterr et al., 2005). The MERK and HAZUS aggregated damage costs are not so disparate. However, when comparing building and contents damage, a significant difference can be noticed between the results these methods generate. This is mainly due to different damage percentages assigned to each flood level, and the empirical data used to create depth–damage curves. The HAZUS method is based on tax-lot level information, the smallest geographic unit for which properties statistical data can be collected, and contents values as a percentage of structural values, while MERK is based on field surveys of different types of buildings, and inventory values derived from household insurance companies. The HAZUS alternative could be considered as a more refined flood damage assessment tool, because the scale of input data is more suitable in the BA context. The HAZUS tool has been applied to Manhattan, New York, U.S.A., where building characteristics (construction type, materials used and age) seem to be more similar to building characteristics in BA. In contrast, the MERK method has been used satisfactorily in Schleswig-Holstein, Germany, where building characteristics are not so similar to BA (Karamouz et al., 2016; Markau, 2003 as cited in Sterr et al., 2005).

Nevertheless, it could be concluded that both methods overestimate damage values, since the direct damage in BA from the most recent flood (in April 2013) was equal to USD 300 million (World Bank, 2016), while results obtained for a single building category — using both methods — yielded loss estimates in the billions of USD. Therefore, there is a great need to develop a flood damage database and to adjust depth–damage functions to local conditions, land use and flood loss data.

The flood loss index. The analysis of FLI yielded dissimilar results in absolute flood loss costs in the worst-case scenario (the year 2070–10-year return flood), because it not only covers residential, industrial and commercial structural and contents damage, but also the relationship with the flood-exposed area and assets. The MERK- and HAZUS-aggregated damage costs are not that disparate, as can be observed in Figure 21, except for the neighbourhood of Palermo. The different rankings obtained after the calculation of FLI and absolute values highlight the importance of choosing an appropriate quantification method, and of interpreting results according to local conditions, especially when using the FLI as a decision-making tool. Treading carefully with the FLI is also necessary because the aggregation of variables can mask certain variables, yielding incorrect conclusions.

Damage reduction. More savings can be achieved with longer flood warning times, which highlights how important it is to develop a warning system and to train people on how to respond to it. The estimation of damage reduction we undertook in this research can be refined using site-specific empirical data describing large-scale mitigation measures, people's responses to warnings, their ability to protect their properties and their ability to shift movable equipment to second storeys.

Additional costs. In addition to building and contents damage, flood impacts can increase when clean-up and emergency response costs are high. The clean-up expenses incurred per property were generated through running scenarios for BA were significantly lower than those reported in the U.K. by Penning-Rowsell et al. (2005), who classified costs based on flood depth below and above 0.1 m (£ 5,725–£ 9,985 or USD 7,583–USD 13,226.13), and those reported in an Australian study, which were AUD 4,000 (USD 3,144) (Bewsher Consulting Pty Ltd, 2009) a figure inflated by including the cost of time and money spent in alternative accommodation. Regarding road clean-up, contractors might be needed to cope with the extra time required to remove flood debris, like sediment, branches damaged trees, waste or wreckage, from roads and drainage pipes in BA. Furthermore, emergency response costs in BA can be diminished if further investment is made in flood prevention measures and education to decrease dangerous behaviours during flood events.

Economic factors. Total building damage and additional costs can also change based on other economic factors. Fluctuations can be marked, particularly in Argentina, where the economy is quite unstable and annual inflation in 2016 reached 30% (Gasalla, 2017). Variables like inflation, population growth and land development may increase losses, while deflation, vacant properties and flood mitigation measures may reduce losses.

Flood mitigation. The implementation of flood mitigation measures can potentially attenuate the flood impacts analysed previously. The extent of the profits the city of BA could realise in implementing additional flood risk reduction measures has significant implications.

Those who do not benefit, or who partially benefit from flood adaptation strategies but still contribute to their development by tax payments or other means, are usually forgotten in the cost–benefit analysis of flood mitigation programmes (Penning-Rowsell & Pardoe, 2012). For instance, certain households do not directly benefit from flood risk reduction as their properties are outside the hazard area, but they may profit from the fact that their jobs or the entertainment facilities they use are not as frequently flooded. They may also derive satisfaction from the pleasure of charitable giving. Other people may also benefit from the conversion of low-value floodplains to other, higher value uses. At the same time, certain people may be affected by a reduction in flooding, particularly those in the construction industry and emergency services, who tend to experience greater demands and higher stress levels in the recovery process after large flood events.

Even though some social groups are willing to pay for the protection of others, as reported in the U.K. and U.S. (Messner et al., 2006; Shabman et al., 1998), the acknowledgement of both "winners" and "losers" and the implications is paramount in risk reduction analyses, because this factor can influence the success of flood adaptation measures. The existence of losers might imply the development of an undesired response, disengagement with emergency planning or conflicts between different societal groups (Penning-Rowsell & Pardoe, 2012). A contribution to flood mitigation proportional to the benefits reaped might be the solution for BA (Benn, 2009).

Cost–benefit analysis can be a useful tool to determine the practicality of flood mitigation. In 2016, the World Bank presented a cost–benefit analysis of implementing various measures in BA, such as improvements to the drainage system, the addition of retention ponds and educational programmes in the Maldonado and Vega Basins, where floods are frequent. The outcomes of this analysis showed that the benefits are double the total costs (World Bank, 2016). The group that would benefit the most would be those living or renting properties (approximately 90% of beneficiaries) in flood-prone areas, followed by those using the road network running through the floodplain. If cost–benefit ratios are estimated properly, then flood protection costs can be distributed between a larger number of stakeholders, including the local community, the city, provincial and national governments, the private commercial sector and tourists (Jeroen et al., 2014). However, cost–benefit analysis should not drive decision-making of itself, because it is sometimes based on incorrect assumptions and imprecise data, which can lead to inaccurate results and consequently, locally unsuitable decisions and regulations.

The flood mitigation strategies that have been implemented in BA so far include structural and non-structural measures, and a more integrated flood management system, including prevention, mitigation and response features. Structural protection measures have included increasing the drainage system capacity and installing retention ponds. Non-structural measures have comprised updating of the urban and emergency legal framework, the country's climate change action plan and new institutional arrangements (e.g., the formation of the Committee for Emergency Attention and the Flood Risk Management Council). Improvement measures thus far have also included the formation of international partnerships (e.g. the C40 Cities Climate Leadership Group and the Union of Ibero-American Capital Cities). Also, a hydrometeorological alert system "SIHVIGILA", relocation of vulnerable communities living by the Riachuelo River and response training for vulnerable groups and public agencies (GCABA, 2015a), has been implemented in BA.

Other measures that should be investigated by BA authorities are amphibious (floatable) constructions, temporary flood protection measures and the formation of evacuation routes along elevated topographical land features. The advantages and disadvantages of each measure are described in Appendix A. Some of these measures can be time consuming, like updating the legal framework, or they may require training or specific professional skills and big investments, as for the construction of reliable flood protection.

A dynamic adaptive policy pathway can be a useful tool to implement flood mitigation measures in BA. It is a decision-making approach designed to be robust to climate change uncertainties, and it allows flexibility over time when modifying flood adaptation plans. This approach has been used successfully to implement the Thames Estuary 2100 project in the UK, the Rhine-Meuse delta project in the Netherlands and flood protection measures in New York City (Haasnoot, Kwakkel, Walker, & ter Maat, 2013) (Figure 22). This methodology caters for uncertainties created by a lack of information and is especially relevant to planners in developing countries, such as Argentina (Reeder & Ranger, 2011). It helps authorities determine for how long a decision can be postponed based on, for example, sea level rise scenarios, and it helps planners identify the triggers, like inundation levels, that predicate different actions in a flood adaptation plan.

In Figure 22, starting from the current situation (vertical gray line), flood damage reduction targets begin to be missed after a short period of time. Action A (red line) and B (light-blue line) should be able to achieve basic protection in coming decades. For instance, low-cost/low-regret actions (A), such as sandbagging, will not be enough to cope with floods in the 2030 scenario generated here, where the maximum flood depth will be 6 m. Then, a tipping point is reached within coming decades; a shift to actions C (green line) or D (yellow line) will be required to achieve the targets. Action D, relocation of buildings, will achieve the targets. Importantly, the dynamic adaptive policy pathway provides more equity to stakeholders because it allows for intergenerational decisions.

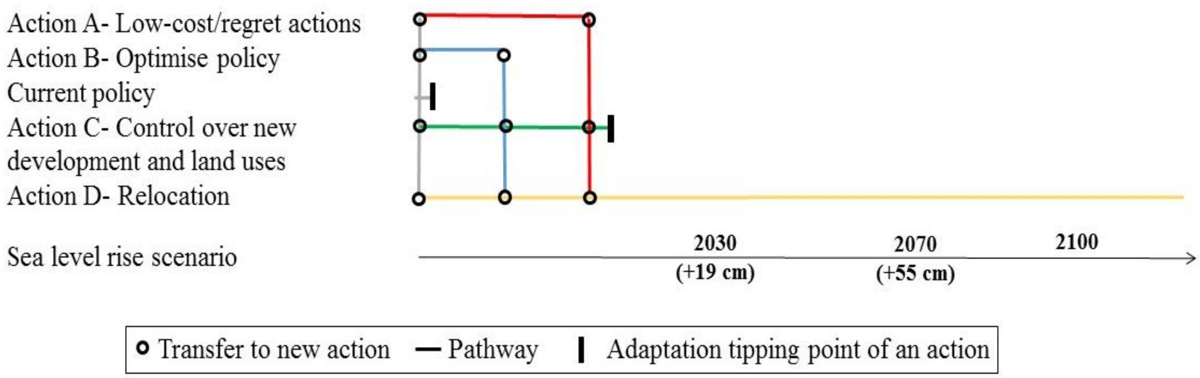

Figure 22. A dynamic adaptive policy pathway (Haasnoot et al., 2013) adapted for BA flood mitigation.

Public flood mitigation schemes are not able to eliminate flood risk completely, and they comprise long-term investments. Consequently, they are not appealing to governments who work in a 4-year election cycle. This is why private or individual mitigation measures are important to complement public mitigation schemes. The use of water barriers, water-resistant constructions materials, flood-adapted buildings and flood insurances are clear examples of individual flood mitigation measures that could work for BA residents and businesses.

Research Limitations and Potential Improvements

In this section, the assumptions behind this research are presented, as are limitations to the methods used, along with potential improvements that can be incorporated in future research. A summary of limitations and improvements is illustrated in Table 9. Also indicated are overestimates, underestimates and neutral estimations for flood damage in BA (Table 9).

Table 9

Research Limitations and Improvements

Assumptions and limitations	**Implications for model**			**Potential improvements**
	(-)	**(+)**	**(+/-)**	
Flood model and georeferenced data				
Inundation model assumes static coastal–estuarine morphology				Include model of coastal dynamics
Flood model has low resolution (73 × 73 m cells), broad flood depth increments (1 m), non-updated baseline, and only accounts for river flooding				Use a high-resolution digital elevation model (DEM). Update baseline (1990) to the 2000 decade. Integrate surface flooding and conditions preceding and following a flood event (e.g., saturated soils due to previous precipitation), and future changes in flood risk (e.g., changes in drainage system) (Remo et al., 2016)
Georeferenced data projected on different systems had to be converted to Posiciones Geodesicas Argentinas (POSGAR) 2007.				National and local institutions should establish a unique coordinate system so as to create a unique georeferenced database that facilitates data sharing

Damage assessments				
Use of generic depth–damage curves developed in the US (HAZUS method) and Germany (MERK method) limits accuracy in local BA scenarios				Develop depth–damage and restoration curves with local experts and site-specific data for BA, considering construction materials, local standards, types of building (e.g., detached, semi-detached house or apartment) Extend the study area to better understand indirect effects outside the city
Other hazards are not considered (e.g., surface flooding, flood duration, velocity and debris impacts, the rise of the groundwater table)				Evaluate increased vulnerability due to other hazards or cascading effects
Local statistics are sometimes not comprehensive, and there are low volumes of local literature/observations of flood damage to validate BA flood impacts				Update DesInventar (the disaster information management system) database with official and detailed data Develop post event field surveys with a standardised method to allow future quantitative analysis, development and calibration of depth–damage curves for BA Include questions about experiences in flood events or any type of hazard in the National Census so as to avoid the necessity to develop flood-specific surveys, which implies extra resources (Kim, 2012)

Building damage				
Unpublished, undetailed or outdated census (2010) and building data (with no specifications about building type, age, construction material, storey, floor area or height) were used				Update building inventories and socioeconomic data when more information becomes available after the 2020 census is conducted
Damage to residential housing assessments were developed at the meshblock level, the smallest geographic unit for which statistical data is collected and processed during a Census.				Develop a land-use database with building and contents values at the tax-lot level, the smallest geographic unit for which properties statistical data can be collected, similar to HAZUS (FEMA, 2017) and HOWAS (Geo Research Center [GFZ], 2015) that contain national data for buildings, facilities, lifelines and hazard data in the US and Germany, respectively.
Industrial and commercial damage estimates only consider buildings that have been surveyed and georeferenced by the local BA council				
Contents values are taken as a percentage of building structure values				

Public infrastructure damage and building damage reduction equations were developed for other countries, where conditions are dissimilar				Calibrate with empirical data from BA. The influences of existing flood mitigation measures and responses to warnings on damage reduction should be further investigated
Industrial and commercial damage figures only consider building and contents damage, not downtime				Include financial losses due to functional downtime
Lifelines & Utilities				
Damage to lifelines and utilities do not take all infrastructural assets into account (e.g., gas, water and wastewater systems)				Create partnerships with service companies to create inventories for more infrastructure assets (e.g., gas, water and wastewater systems) and update utility georeferenced databases
Utilities' service areas are not specified				Statistics describing numbers of users and georeferenced data describing utility service areas would provide practical information leading to an accurate flood impact assessment

Lifelines and utility damage assessments do not consider the variable vulnerability of the systems' components, network interdependency and cascading damage				An evaluation of potentially affected areas should be done with service companies and local experts, as they could provide information on the system's vulnerability and performance during floods, mitigation measures and any improvements that might be in progress
Utility disruption (to hospitals, health centres, schools, telecommunications towers and substations) was only measured in terms of affected people				Consider infrastructure damage and losses based on average daily expenditure per student/patient/client and functional downtime.
Transport disruption				
Economic effects caused by transport disruption were only measured in terms of ticket value loss				Include infrastructure losses and increases in travel time
Indirect effects on areas outside the flood-prone area were not considered				Areas outside the flood-prone area can experience indirect flood impacts since transport in and out of the city can be affected when road access and transport services are limited during floods, which should be added in future flood damage assessments

Vehicle damage				
Vehicle damage assumes an even inundation (0.3 and 0.6 m), and that vehicles will be in the inundated area all at the same time				Increase historical flood depth accuracy and traffic data
Clean-up costs				
Road clean-up costs were developed with average road width in mind				Develop a detailed road network with actual road widths included
Building clean-up costs do not consider property size or type of flood water (e.g., clean/grey, flood/storm, flood waters including sewage and contaminated waters)				Consider property floor areas, types of flood water (e.g., clean/grey, flood/storm, flood waters including sewage and contaminated waters) Post flood clean-up costs should be recorded in future flood events to calibrate calculations
Flood loss index				
Use of weighting factors was not 100% representative				The flood loss index should be used as a primary analysis tool to identify exposed areas Further analysis should be done, preferably at the tax-lot level, the smallest geographic unit for which properties statistical data can be collected, to better understand factors influencing flood exposure and loss

Emergency costs				
Emergency response cost equations were developed for other countries				Emergency costs should be recorded in future flood events to calibrate calculations

Note. (-) refers to underestimates, (+) to overestimates, and (+/-) to neutral estimations for flood damage in BA.

Conclusions

Flood impacts operate on different time scales, with short- to long-term effects, and are not limited to within the BA city boundaries. Estimates of population numbers affected by damage to infrastructure lifelines and utilities should be considered to facilitate the supply of alternative power sources or telecommunications networks, and also when evacuation modelling, because services disruptions can predicate evacuation even when households are not flooded. In addition, evaluating the impacts on hospitals, health centres and schools can help emergency managers to identify which other facilities will need more resources to cope with increasing demand and to inform people of where the closest unaffected facilities are.

Flood effects on vehicles on the road during non-working hours in a 0.6 m flood represent the worst-case scenario in BA, as according to our research, USD 266 million loss is expected. Warnings play an important role in avoiding vehicle-related fatalities (e.g. electrocution or drowning) and lost value for vehicles, as people might be able to move their vehicles to safe areas before inundation occurs.

In BA, models presented here show that significant building damage is caused in relatively minor floods (e.g. the 2- and 5-year events). There will be a considerable increase in losses as the severity of flooding increases in future scenarios (e.g. the years 2030 and 2070). Mapping showed that flood damage in BA should be relatively evenly distributed throughout the flood-prone area and probably will not be concentrated in any single neighbourhood, except for industrial damage, which would probably be greater in the south of BA. According to the results of this research, the highest damage costs throughout the flood-prone area were sustained by the commercial sector. A small group of census blocks suffered higher residential building damage than their surrounding cells, mainly caused by significantly higher land prices or housing density. Naturally, our calculations of losses increased when emergency, clean-up and repair costs are added.

Flood loss figures derived from the FLI indicated that Parque Avellaneda, Flores, San Telmo, Villa Lugano and Recoleta should be the most affected neighbourhoods in terms of building damage and exposed area. However, losses measured in absolute values shows that loss would most likely be concentrated in the Belgrano, Villa Soldati, Palermo, Barracas and Nueva Pompeya districts. Special attention is therefore needed for the interpretation of results and to make results practicable for use by BA emergency response management.

Moreover, the city centre is located in the flood-prone area, which will impact on the administrative, commercial and cultural activities. Decentralisation of key assets outside the flood-prone area could reduce vulnerability and the time people are left without access to services. Even though flood disruption of certain activities and sectors probably cannot be avoided, the level of disruption and recovery time can be diminished. Restricting construction and prioritising low-damage land use (e.g. parks, playgrounds and carparks) in high flood risk areas can also improve the city's resilience to floods.

Uncertainty remains in these results because documented impacts from previous floods are not always publicly available, and local BA statistics are not comprehensive. Nevertheless, the work presented herein demonstrates the feasibility of using disparate datasets, combined with reasonable assumptions and established modelling approaches, to provide preliminary damage assessment estimates, to identify critical flood prone areas and to implement potential improvements to emergency response plans.

The results of the current impact assessment can be used as a baseline to assist the BA council in future assessments, in the articulation of the city's hydraulic master plan and in the coordination of preventive and response activities, with focus on the areas identified as highly exposed. Furthermore, the findings of this research substantially enlarge the area that BA planners need to focus their mitigation efforts on, as only areas that are prone to waterlogging have been identified so far, and the flood-prone area demarcated in this study is far larger. As described by Stephens (2015), planning efforts addressing sea level rises and floods should be spent on increasing adaptability within short periods of times instead of concentrating only on the magnitude of the event. In other words, enhancing resilience should be a priority regardless of flood recurrence or the rate of sea level rise.

Chapter 3

Evacuation and Emergency Response

Introduction

Frequent flooding has been affecting BA since the early stages of urbanisation (Novick, Collado, & Favelukes, n.d.). Approximately 8.41% of BA's population resides in low-lying areas exposed to floods. City authorities can choose to do nothing, avoid, reduce, transfer or mitigate flood risks. Emergency responses and efforts to mitigate flood impacts potentially available to BA authorities include administering medical treatment, effecting rescue or ordering an evacuation (Department of Homeland Security, n.d.). Evacuation can reduce casualties if people know evacuation routes, safe areas and are proactive about arriving at these areas before a hazardous event (Knook et al., 2015). Research has shown that different percentages of populations evacuate to different locations during emergencies. For instance, in the U.K., 42% prefer to go to evacuation centres, 38% to friends and family, 9% to hotels and 11% to other types of accommodation (Penning-Rowsell et al., 2013), whereas in the U.S. State of California, only 12% look for accommodation at evacuation centres, 48% house of a friend or relative, 14% prefer hotels, 15% other, and 11% do not know (Alabdouli, 2015).

Diverse types of evacuation can be carried out, small or large scale, pre- or post-event, immediate or pre-warned. Pre-warned evacuation can be either voluntarily, or mandatory. Voluntary evacuation is triggered when there is a considerable actual or perceived risk, and people move without being told to do so (New Zealand Civil Defence, 2008). This type of evacuation can benefit or hinder emergency management, as there may be too few people left in flood-effected areas to assist, or more people may put themselves in danger if they evacuate at the wrong time and encounter, for example, severe weather conditions while en route to shelter.

A mandatory evacuation is issued when risks are considered to be significant by authorities, and is only advisable when the risk of remaining is greater.

Emergency managers need to organise the evacuation process efficiently, and via designated routes, to guarantee people's safety. Effective official communication can reduce anxiety and the effects of dangerous behaviours, and can increase the chances that people will follow instructions during evacuation (New Zealand Civil Defence, 2008). Evacuation can be divided into the following phases, which require different resources and staff (New Zealand Civil Defence, 2008):

- the decision to suggest evacuation versus "shelter-in-place",
- issuance of a warning and required actions,
- oversight of the evacuation,
- oversight of shelters, and
- organisation of the return-to-home process.

Evacuation modelling can optimise real evacuation times and clearance. The complexity of modelling evacuees and potential routes lies in the interaction of different disciplines, such as transport planning, engineering and the social sciences. Environmental, social and infrastructural factors such as land slope, weather, time of day, planned social events, road conditions and travel modes affect evacuation. Demographic variables and evacuees' physical and psychological conditions, behaviour (Buckland & Rahman, 1999; Drabek, 2000; Handmer, 2000), risk perception and behavioural response to official warnings can also affect evacuation, but these factors are often too complex to model (Lindell & Prater, 2007).

Over the years, several evacuation models have been implemented for various hazards. The most commonly used are ABMs and GIS analyses, such as the LCPD model. The ABM models explore interactions between, and decision-making processes of, individuals and organisational agents in a system, based on their roles and empirical, or theoretical, characteristics (D'Orazio et al., 2014; Medina et al., 2016; Yin et al., 2014). The discipline demands a good working knowledge of population behaviour, which is site-specific, or if such knowledge is not available, the development of surveys to gather information to be used as input into the model. The LCPD ignores social variables. It includes only environmental factors, such as vegetative land cover and topography, to estimate the minimum cost of travel to evacuation sites, which is derived from route length, time spent evacuating and energy (e.g. fuel). The LCPD approach is suitable for both vehicle and pedestrian evacuation models. It has been implemented, for example, for tsunami evacuation of Sumner Beach, New Zealand (Le, 2016) and in the U.S. State of Washington (Wood et al., 2016).

Commonly available GIS-based approaches are ideal for evacuation modelling. The network analyst tool in ArcGIS is a network-based spatial analysis tool that allows researchers to model routes based on the shortest path approach. The network analyst tool also facilitates modelling of "barriers" that restrict or alter traffic flow, such as traffic lights, railroad crossings and flooded areas. Another GIS-based evacuation approach that has recently been developed is the capacity-aware shortest path evacuation routing (CASPER) tool, which is based on the same concept as LCPD and incorporates variables directly related to transport. The CASPER evacuation model has been used successfully for tsunami evacuations in the U.S. State of California (Alabdouli, 2015) and in Tauranga, New Zealand (Knook et al., 2015). In California, private vehicle evacuation was modelled by considering variables like number of vehicles and shadow evacuation zones, initial delay costs, saturation density of a road with one unit of capacity (e.g. one lane) and congestion (Alabdouli, 2005). Evacuation routes in Tauranga were analysed by zone, from high-hazard zones (fatality likely) to areas of low hazard (fatality unlikely), followed by an analysis of points of safety (safe zones) (Knook et al., 2015).

In summary, evacuation models are a good decision support tool during planning and emergency response phases because they allow authorities to estimate travel times, and they inform decisions about how best to accommodate evacuees at evacuation centres based on available resources, equipment and facilities. Therefore, in Chapter 3, evacuation routes for both vehicles and pedestrians caught in different flood scenarios in BA will be modelled. The aim is to inform flood emergency management in BA, because no models have yet been published for the city. The capacity of emergency facilities to serve the BA population based on evacuation service areas will be also investigated in Chapter 3.

Evacuation Planning in BA

The city of BA has been subject to evacuations in the past, and there is a clear need for evacuation modelling. The last flood event in BA resulted in the displacement of more than 550 people in February 2005 ("The April storm," 2013). In October 2012, 20 families were evacuated from slum numbers 21 and 24 ("Storm in the city," 2012), and in April 2013, 300 people were evacuated, with an additional 350,000 people affected in the neighbourhoods of Saavedra, Belgrano, Núñez and Palermo ("Almost 50 deaths," 2013). Following these severe events, the city council started work on improving the urban and emergency planning legal framework, institutional arrangements and warning systems.

The urban planning framework developed for BA during the 20th Century has been characterised by a non-integrated approach of environmental and socioeconomic components (Clichevsky & Herzer, 2000), a lack of coordination between the city and suburban areas and inconsistencies in the classification of permitted and prohibited activities throughout time, like construction in flood-prone areas. This non-integrated urban planning approach has contributed to an increase in the city's vulnerability to floods (Koutsovitis & Goyeneche, n. d.; Clichevsky & Herzer, 2000).

Improvements have been made with the introduction of the *Urban and Environmental Plan* (Ministry of Planning and Public Works [MPyOP], 2006), the *Strategic Plan* (GCABA, 2015b), and the *Action Plan in Face of Climate Change 2020* (GCABA, 2015a), which adopt a more integrated management approach to biophysical and socioeconomic aspects of flood emergency planning, and facilitate cooperation between the city council and other municipalities. These three plans propose general measures to adapt and to mitigate natural hazards and climate change. In addition, new urban (MDUyT, 2017a) and building codes (MDUyT, 2017b) are being developed via a consultation process and with the input of public opinions. Furthermore, Argentina is currently developing a national plan for disaster risk resilience (DRR), based on the *Argentina: Sendai Framework Data Readiness Review Report* (UNISDR, 2017), and at the city level, an emergency management plan (known as the *Plan Director de Emergencias*) (GCABA, 2009) has been prepared that establishes responsibilities for each local governmental agency in the occurrence of an emergency.

The revised legal framework and new institutional arrangements described by these documents have evolved over time. Authorities have now acquired diverse tools to reduce flood vulnerability. However, the efficiency of new systems and tools is still questionable, and more work needs to be done to develop comprehensive evacuation strategies and modelling. This gap is readily apparent, as no published literature describing evacuation models for BA exists. Therefore the following presents the first comprehensive treatment of modelling spatiotemporal population exposure, evacuation dynamics, and receiving facility capacities to inform emergency response.

Methods

Spatiotemporal exposure to floods. To address the BA flood modelling gap, first the extent of the flood-exposed population in BA was estimated in different flood scenarios (1990, 2030, 2070) by intersecting the Lecertua (2010) BA flood model with census centroids representing 2010 Census meshblocks containing numbers of households and people. Demographic characteristics such as age, gender, deprived households and income levels were also considered, because they are crucial factors that influence social vulnerability.

Evacuation analysis. Estimates of households potentially requiring evacuation were based on flood depth and evacuation probability, and were calculated by intersecting the Lecertua (2010) BA flood model with census centroids containing data describing number of households and people living in flood-prone areas. Penning-Rowsell et al.'s (2013) minimum and maximum evacuation probabilities (23% for a 0–1 m flood and 87% for a >1 m flood) were used to create a BA flood model describing flood scenarios, where waters increased by 1 m increments.

Evacuation routes. In this research, diverse evacuation scenarios were also analysed. The Environmental Systems Research Institute (ESRI) online road network data (ArcGIS, 2012) and the closest facility online tool were used, which are included in the ArcGIS 10.3 network analyst toolkit and is a network-based spatial analysis tool (Figure 23).

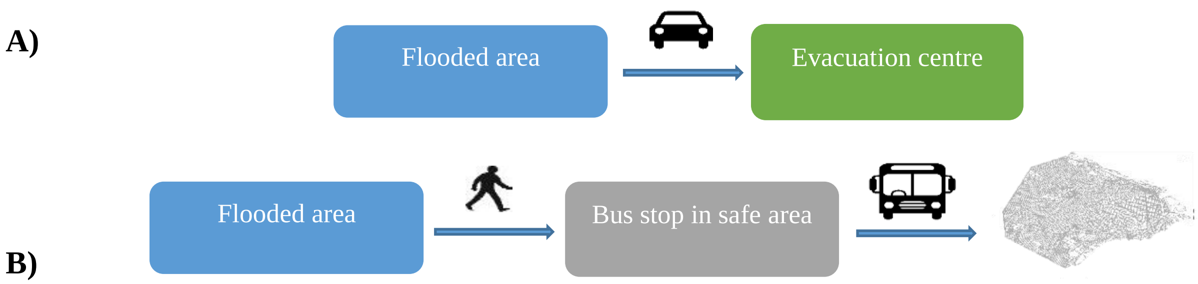

Figure 23. Evacuation scenarios for BA. In scenario A, people evacuate by private vehicle from the flood-prone areas to evacuation centres and in scenario B, people walk to bus stops in safe areas for subsequent evacuation to accommodation outside hazard zones.

In scenario A in Figure 23, people evacuate by private vehicle from census centroids in the flood-prone areas to evacuation centres. In scenario B, people walk to bus stops in safe areas for subsequent evacuation to accommodation outside hazard zones. This use of multiple transportation options is important in BA, as many people do not have private cars and depend on public transport, particularly buses, which are the preferred means of transport in the city (Secretaría de Transporte, 2007). In this model, it is assumed that buses (capacity = 33 passengers each) would be provided by Buenos Aires Civil Defence, because this agency is responsible for transporting evacuees, as established by the *BA Emergency Management Plan* (GCABA, 2009).

The following assumptions were also made for the evacuation model:

- In the year 2070-10 year return flood scenario, an inundation of higher than 1 m was assumed to cause maximum evacuation (87% of total households), and the minimum evacuation probability (23% of total households) was assumed to be the result of < 1 m floods (Penning-Rowsell et al., 2013) (Table 10).

- Also assumed is that early in the morning and at night, all populations living in the flood-prone area would be at home, but that different percentages of households would receive flood warnings depending on time of day. Further, it is assumed that 25% of households would respond to evacuation warnings at night, as the remainder would be asleep. Assumptions are based on the approach taken by Bewsher Consulting Pty Ltd (2009), where they assumed 25% and 90% of vehicles wold be on the road during working and non-working hours, respectively.
- For the purposes of creating a workable model, all populations living in the flood-prone areas were assumed to be at home both on weekends and during weekdays. Travel time variations between weekdays and weekends were based on ESRI's traffic database (ArcGIS, 2012).
- Statistics describing tourists arriving at Jorge Newbery Airport, BA were accessed to estimate seasonal increases in evacuee numbers in summer versus winter (GCABA, n.d.). Similar to non-tourists, 42% of tourists were assumed be evacuated to evacuation centres in Parque Pereyra, Martin Fierro and Colegiales, which are located close to neighbourhoods tourists commonly frequent. Tourists arriving by vehicle, ferry and long-distance bus were not considered due to lack of available data.

Table 10

Evacuation probability, households in receipt of warnings and evacuation destinations

Evacuated households in >1 m flood	Evacuated households in >1 m flood	Households in receipt of warnings during the day	Households in receipt of warnings during the night	Households/tourists in receipt of warnings who make it to evacuation centres
23%	87%	90%	25%	42%

Note. Evacuation data sourced from Penning-Rowsell et al. (2013) and percentage of households in receipt of warning was based on the approach taken by Bewsher Consulting Pty Ltd (2009).

- Vehicle evacuation modelling included the entire BA road network. A restriction was set to avoid pedestrian streets because their width tends to be inadequate for vehicles, and therefore, they are used only for pedestrian evacuations. Vehicle speeds were set according to the speed limit of each road class. Nonetheless, in case of an emergency, drivers might exceed the speed limit due to panic, or be forced to reduce speed because of congestion.
- For pedestrian evacuation models, pedestrian-only streets were included and highways were excluded. Previously published research was used to set minimum (0.88 m/s), average (1.43 m/s) and maximum (2.8 m/s) walking speeds (Fraser, 2014).
- Departure time, defined as the time needed by evacuees to start movement towards a place of safety (Cuesta, Abreu, & Alvear, 2015), was set at 5 minutes to account for obstacles and impediments like stairs, elevators and disabilities, which can delay departure time.
- Models included evacuation centres located outside the flood-prone area, in Parque Pereyra, Martin Fierro, Chacabuco, Avellaneda, Dorrego, Pomar, Costa Rica and

Colegiales. These centres' capacities were modelled based on information obtained from risk operational management in BA Civil Defence (G. Barbaresi, Civil Defence, personal communication, September 8th, 2017).

- All evacuees were assumed to choose the same means of transport (i.e. bus or private vehicle) to evacuate.
- The number of people who evacuated to designated centres was based on figures obtained from U.K. research (Penning-Rowsell et al., 2013). The larger study area modelled in the U.K. research was better matched to the size of the BA flood-prone areas. Similar research in the U.S. considered only Orange County, a single county in California (Alabdouli, 2015). Furthermore, Penning-Rowsell et al. (2013) used a greater percentage (42%) of people evacuated to designated evacuation centres, which might be more appropriate for developing cities as BA, where less people might be able to afford private accommodation.

Post evacuation dynamics. The number of evacuees, and costs to evacuated households remaining in temporary accommodation after evacuation, were based on the percentage of households initially evacuating to shelters (42%) and hotels (9%) (Penning-Rowsell et al. 2013). Models also took into account the average price for a room in a one- or two-star, three-star hotel and aparthotel in BA in 2017, which was USD 32, USD 40, and USD 55 respectively (GCABA, n.d.).

Emergency response dynamics. Interviews were conducted with local authorities and Civil Defence to obtain an overview of current measures in place for flood control and emergency response, and to identify opportunities for improvement. Participants were selected from the council's website staff list, dependent on their roles in emergency response. Interviews were developed under the specifications of the Human Ethics Committee of the University of Canterbury, New Zealand, and included questions about flood control infrastructure, urban planning, future projects to reduce flood vulnerability, risk management software, agreements between local agencies and other institutions, the strengths and limitations of BA emergency plans, climate change, sea level rises, flood models, the welfare of evacuees and communication methods used during emergencies (Appendix B).

Emergency response service areas. In BA, administrative boundaries, based on groups of neighbourhoods, are used to set up fire station service areas (Figure 24), the part of the city in which fire brigades provide service. However, it is uncertain that administrative boundaries are the most efficient way to set up service areas to respond to emergencies, because different administrative areas might contain diverse populations, with a huge variance in population density, which means that fire stations may in fact be overwhelmed by an excessive workload, and may have to re-assign resources accordingly. Travel distance from fire stations was considered a better way to establish service areas and as a way to improve emergency response capacity. Existing staging points, sites where fire brigades and Civil Defence are located in case of meteorological warnings to offer a faster response, were also considered.

Based on travel distance, an analysis of fire stations and staging points service areas was performed using the service area tool in ArcGIS 10.3, which encompasses all streets within a specified distance from a particular station or staging point. The existing BA road network (Mapzen, n.d.), fire stations (16 out of 28) located outside the flood-prone areas were used, identified by the local council (GCABA, n.d.) and Lecertua (2010), and 14 existing staging points to determine the potential service area of each facility in scenarios with and without floods. The tools and road network data we used in this analysis were computer-based, instead of online, because machine-based tools allowed us to upload more "polygons barriers" (e.g. flooded areas) and to more freely simulate how floods would affect emergency response capacity.

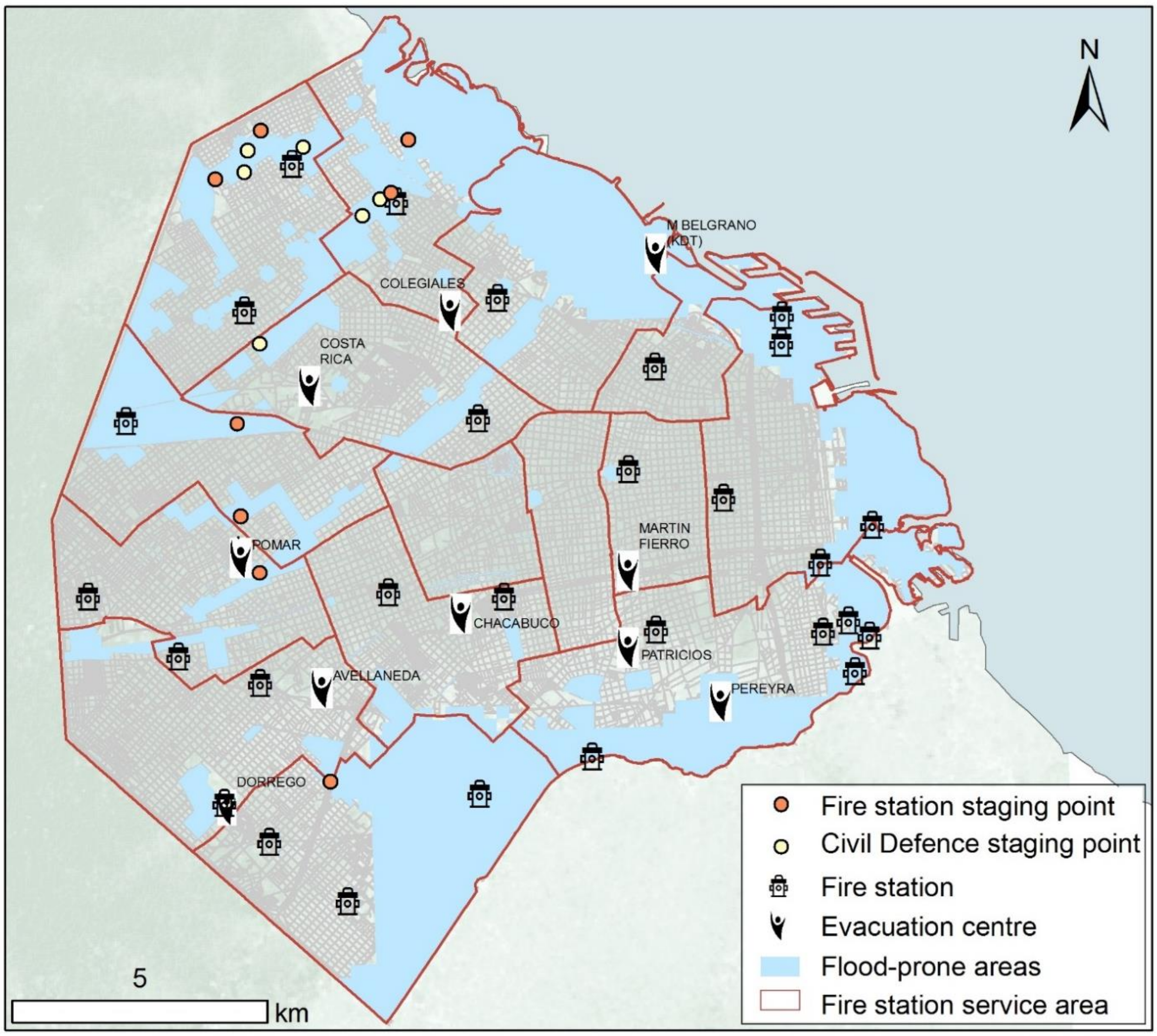

Figure 24. Current BA emergency service facilities.

Fire stations and staging points service areas were delimited based on distance (2, 5 or 8 km) from fire stations. Populations living within the service areas were calculated by intersecting census centroids with service area polygons.

Also considered was travel distance from fire stations and staging points in the 2070 flood scenario. Polygon barriers in ArcGIS simulating river flooding and waterlogged areas were added to the analysis to better reflect reality or delays in emergency response. The costs, reflecting the difficulty in traversing flooded areas, were apportioned by applying different multiplication factors (2, 5 and 10) in travel distance.

Results

Spatiotemporal exposure. Flood modelling results indicated that the population living in the flood-prone areas near the La Plata River (243,200 people) represented 8.41% of the total BA population, reported in the 2010 census (INDEC, 2010), in the worst-case flood scenario (in the year 2070). This population was 51% females, and 65% were elderly people aged between 15 and 64 years (GCABA, n.d.). According to the scenarios generated, Villa Soldati, Palermo, Barracas, La Boca and Retiro's populations were the most vulnerable to floods, because these neighbourhoods have high population density, and more than 45% of their land areas would be exposed to flooding in the 2070 flood scenario.

Approximately 82,300 households (7 % of total households in BA) might experience flooding. A large proportion of flood-vulnerable households (15%) are characterised as deprived households; they are mainly distributed in the south of the city and in Retiro in the east (Figure 25) (GCABA, n.d.). Deprived households, where resources are scarce, will encounter more difficulties in preparing and recovering from floods (Koks et al., 2015). Therefore, emergency aid will be required in these areas. The south of BA is also characterised by high population density, illiteracy, unemployment and low income levels, a full 30% lower than in the north, as measured by average total family income (GCABA, n.d.-a). Income level can be an indicator of household location, type of structure (either water-resistant or not), number of vehicles per household (Page & Adams, 2003) and high dependence on council aid (Kim, 2012).

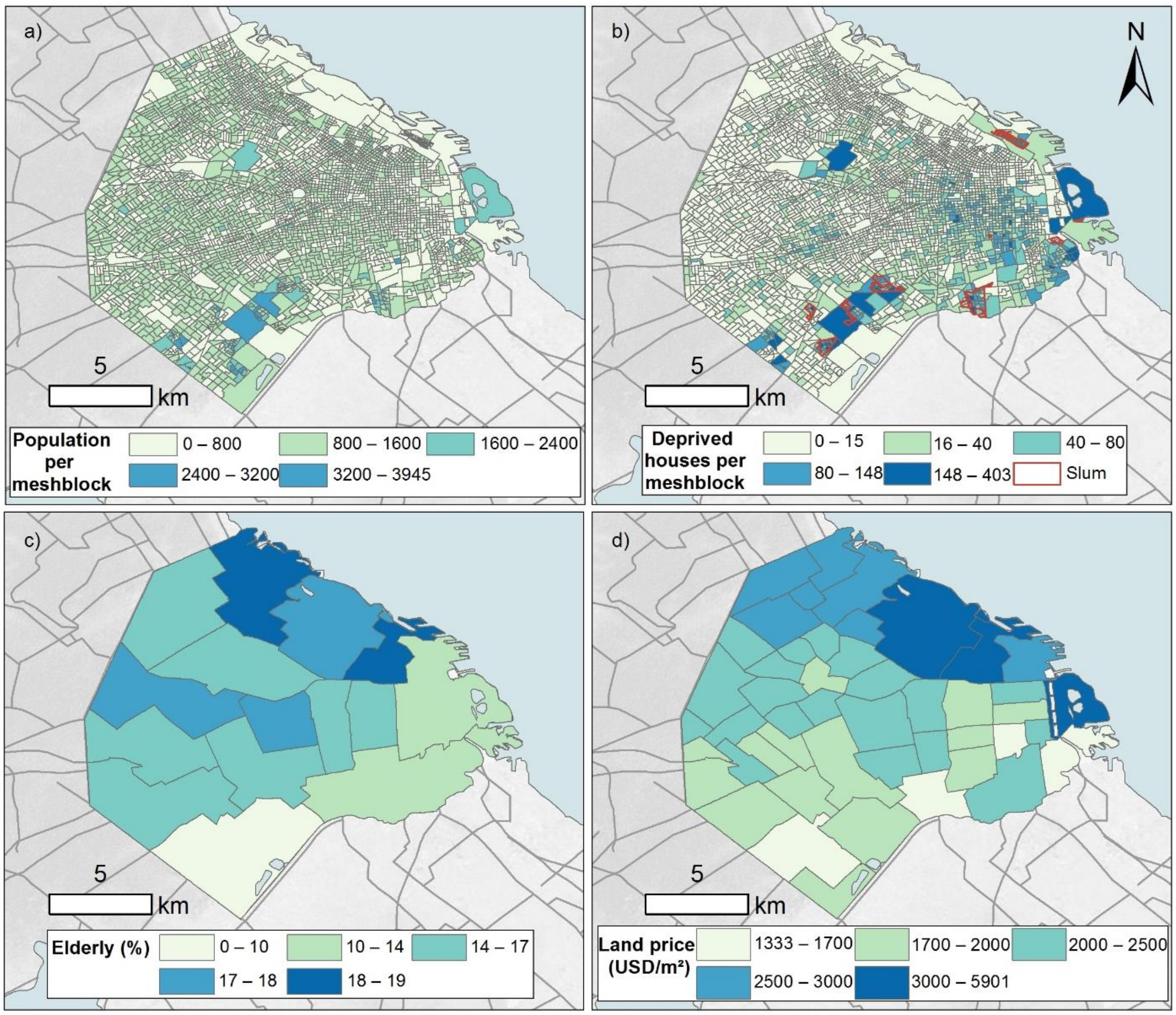

Figure 25. Demographic variables in BA (GCABA, n.d.). a) shows population per census meshblock, b) the number of deprived houses per meshblock, c) the percent of people over 65 years old and d) the land price of each neighbourhood in USD per square metre.

Minimum and maximum values of percent evacuated households were modelled for the 1990, 2030 and 2070 floods, and all return periods (2, 5, 10 years) (Table 11). Minimum and maximum values of percent evacuated households occur in the 1990-2 year return and 2070-10 year return flood, which represent 1.39% and 3.55 % of total residencies in BA, respectively. Evacuation probability increased with inundation recurrence as flood waters rose. To take the 1990 baseline scenario and its return periods an example, evacuated households increased by 8.3% between the 2- and 5-year return floods, and they increased again by 10.4% between the 2- and 10-year return events in the baseline scenario (1990). Results showed that the most affected neighbourhoods were Villa Soldati, Palermo, Barracas, La Boca and Retiro, because of their large land area exposed to flooding. According to results from this research, such a large land exposure will trigger the evacuation of 20,000 households in the least severe flood scenario (the 1990 version). These values could be even higher if additional population displacement occurs when households that are not flooded decide to evacuate as service and utility lifelines to their homes are disrupted. Results reported here may overestimate numbers of evacuees, based on published reports of actual evacuee numbers in previous events ("Storm in Buenos Aires," 2012; "Almost 50 deaths", 2013; "The April storm," 2013).

Table 11

Percentage of evacuated households in different flood scenarios, BA

Neighbourhood	Total households	Flood scenario 1990 Return period (years)			2030 Return period (years)			2070 Return period (years)		
		2	5	10	2	5	10	2	5	10
Barracas	31,249	10	10	10	10	13	16	13	16	19
Belgrano	54,915	2	2	2	3	5	5	5	5	5
La Boca	16,287	16	16	16	16	24	31	24	37	41
Flores	60,248	1	1	1	1	1	1	1	1	1
Núñez	22,700	1	1	1	1	1	1	1	1	1
Nueva Pompeya	14,460	6	6	6	6	8	9	8	9	13
Palermo	102,918	4	4	4	4	5	8	5	8	9
Puerto Madero	2,465	19	19	19	25	38	38	38	39	56
Recoleta	73,156	0.05	0.05	0.05	0.05	0.16	0.16	0.16	0.18	0.18
Retiro	24,147	9	9	9	9	9	9	9	10	23
San Telmo	9,188	1	1	1	1	1	1	1	1	1
Villa Lugano	39,848	4	4	4	4	7	7	7	8	8
Villa Riachuelo	4,782	1	1	5	5	5	5	5	5	5
Villa Soldati	13,574	27	38	38	57	72	84	76	86	87
Total	469,937	19,846	21,491	21,914	25,128	34,286	41,307	35,214	42,998	50,703

Evacuation analysis. The analysis assume 42% of evacuated household go to evacuation centres, while a minor proportion may remove themselves to hotels (9%). The results showed that evacuation centres should be prepared to provide accommodation, food and support to at least 8,335 households in the baseline scenario (the 1990 model), and to 21,295 displaced households, understood as one family, in the 2070 scenario (Table 12). In both scenarios, the number of households opting for hotels was lower, accounting for just 1,786 and 4,563 households, respectively (Table 13).

Table 12

Households accommodated by evacuation centres in flood scenarios, BA

Scenario	Return period (years)	Total evacuated households	1 week	2 weeks	3 weeks	4 weeks	8 weeks
1990	2	19,846	8,335	7,085	4,168	2,917	834
	5	21,491	9,026	7,672	4,513	3,159	903
	10	21,914	9,204	7,823	4,602	3,221	920
2030	2	25,128	10,554	8,971	5,277	3,694	1,055
	5	34,286	14,400	12,240	7,200	5,040	1,440
	10	41,307	17,349	14,747	8,674	6,072	1,735
2070	2	35,214	14,790	12,571	7,395	5,176	1,479
	5	42,998	18,059	15,350	9,030	6,321	1,806
	10	50,703	21,295	18,101	10,648	7,453	2,130

Note. 42% of total evacuated households are assumed to stay in evacuation centres. In the first week following evacuation, 100% of these evacuated households remain in evacuation centres, 85% remain in the second week, 50% in the third week, 35% in the fourth and 10% remain in the eighth week. Analysis adapted from Penning-Rowsell et al. (2013).

Table 13

Evacuated households accommodated in hotels in flood scenarios, Buenos Aires (BA)

Scenario	Return period (years)	*Total evacuated households	1 week	2 weeks	3 weeks	4 weeks	8 weeks
1990	2	19,846	1,786	1,518	893	625	179
	5	21,491	1,934	1,644	967	677	193
	10	21,914	1,972	1,676	986	690	197
2030	2	25,128	2,262	1,922	1,131	792	226
	5	34,286	3,086	2,623	1,543	1,080	309
	10	41,307	3,718	3,160	1,859	1,301	372
2070	2	35,214	3,169	2,694	1,585	1,109	317
	5	42,998	3,870	3,289	1,935	1,354	387
	10	50,703	4,563	3,879	2,282	1,597	456

Note. *9% of the total population is assumed to occupy hotels as alternative accommodation. In the first week following evacuation, 100% of these evacuated households remain in hotels, 85% in the second week, 50% in the third, 35% in the fourth and 10% in the eighth week. Analysis adapted from Penning-Rowsell et al. (2013).

Vehicle evacuation. The evacuation analysis preferentially assigned populations to routes with the destinations of Dorrego, Avellaneda, Martin Fierro, Colegiales, Parque Pereyra and Chacabuco, due to the proximity of these evacuation centres to flood-prone areas (Figure 24). Costa Rica and Pomar were excluded as they are too far away from flood-affected areas. Avellaneda and Parque Pereyra in the south would potentially receive the highest number of evacuees (Figure 26). It should be noted that the number of evacuees arriving at evacuation centres differed per scenario because the ArcGIS (2012) network analyst tool automatically finds the best routes and minimises travel time based on historical traffic data.

Travel time by vehicle from flood-prone areas to evacuation centres tended to be greater during the night than in the morning, regardless of the day of the week, because more cars tend to be on the road during non-working hours (Figure 27). For instance, it was calculated that the average difference between travel time in the morning and night was 0.66 minutes on weekdays and 0.08 minutes on weekends. During weekends, an average reduction in travel time of 1.4 minutes was realised. Evacuation times calculated with ArcGIS were within the range of travel times indicated by Google Maps. Travel times indicated by Google Maps, in agreement with ArcGIS, differed only marginally in the day versus at night, and weekday versus weekend, by approximately 2 minutes (Table 14 and Figure 28).

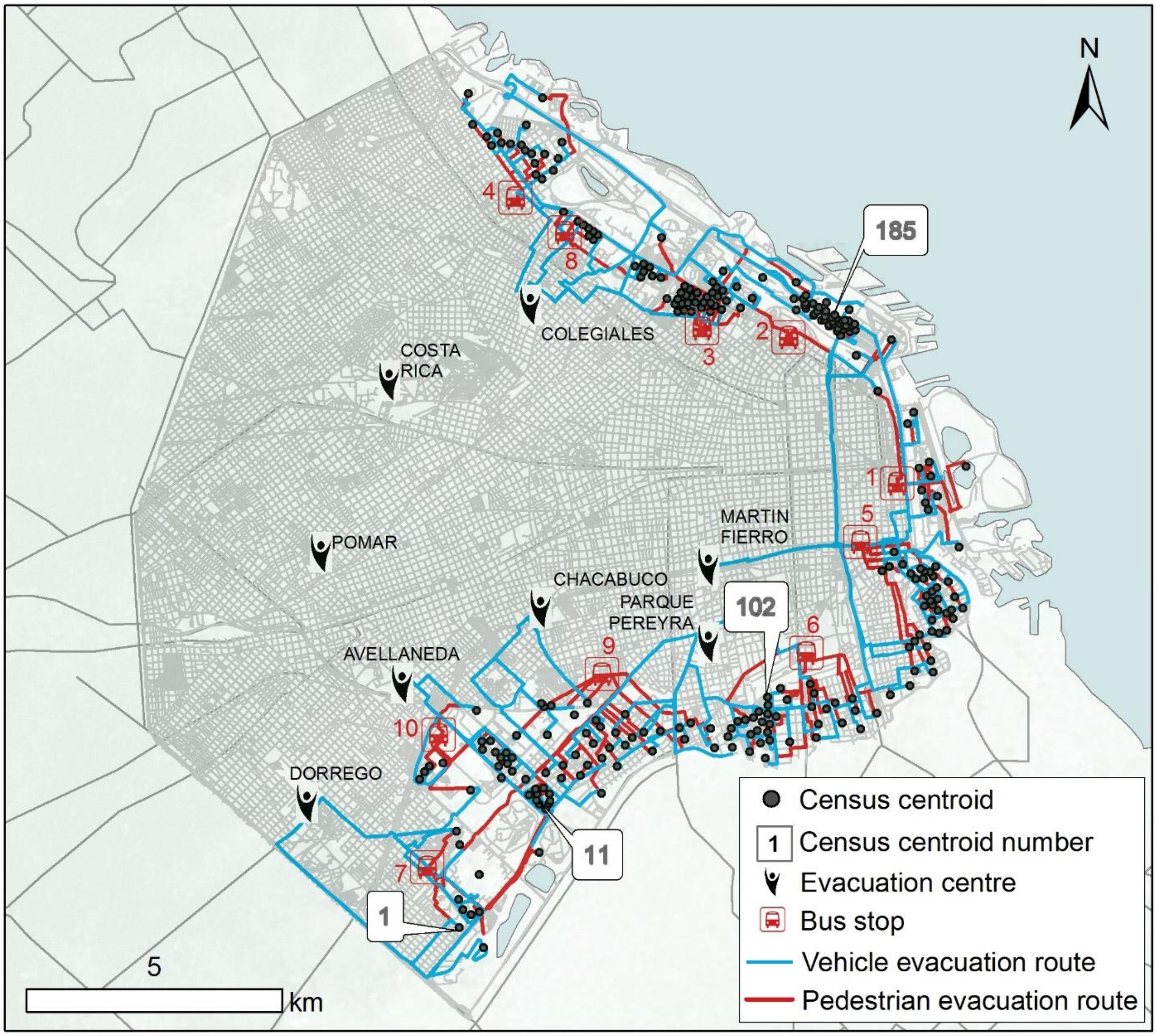

Figure 26. Evacuation routes for vehicles and pedestrians departing from BA census centroids in the flood-prone areas and arriving at evacuation centres, and safe zone bus stops, respectively.

The analysis also showed that the longest vehicle evacuation times would be from the Colegiales, La Boca and Puerto Madero neighbourhoods to the Colegiales (27 min) and Martin Fierro (37 min) evacuation centres, respectively. The average time required by most vehicles to travel from their households to the evacuation centres would be between 16 and 17 minutes across all scenarios. This is true regardless of time of day, season or day of the week.

It must be noted that additional travel time may be required for night scenarios because visibility is reduced at night, and people who are asleep might take a longer time to become aware of inundation hazards and to decide to evacuate. Also, travel times during evacuations at night can be greater because congestion might be more severe than in daytime scenarios. Traversing inundated areas with reduced visibility might add not only travel time, but also total distance as detours might be necessary. Traffic congestion in non-flood scenarios represents, on average, 42% extra travel time ("TomTom Traffic Index", 2016), especially during rush hour, which in BA is from 7–8 a.m. in the morning, and 6–7 p.m. in the evening (Secretaría de Transporte, 2007), so special attention should be given by authorities to evacuation planning around these timeframes.

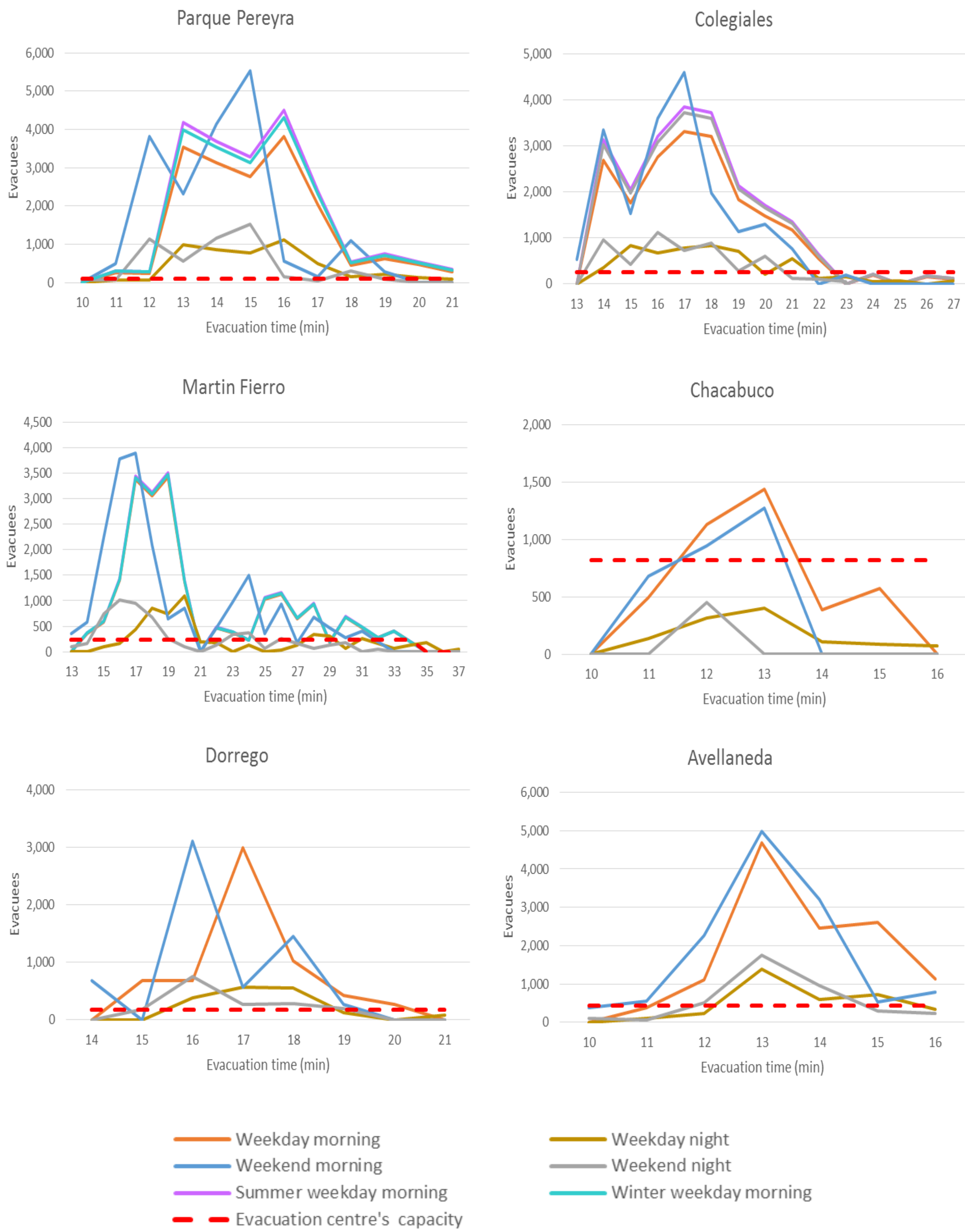

Figure 27. Number of evacuees and evacuation times of people arriving at evacuation centres in BA by vehicle.

Table 14

Evacuation route travel times from census centroids in flood-prone areas to evacuation centres in BA

		Travel time (minutes)							
		Weekday mornings		Weekday nights		Weekend mornings		Weekend nights	
Origin (census centroid number)	Destination (evacuation centre)	ArcGIS	Google Maps	ArcGIS	Google Maps	ArcGIS	Google Maps	ArcGIS	Google Maps
1	Dorrego	15.1	9–18	15.8	10–18	14.3	9–16	14.5	9–16
11	Avellaneda	7.2	5–9	7.2	5–10	6.4	5–9	6.6	5–8
102	Martin Fierro	11.9	10–18	12.8	10–18	10.7	10–16	10.6	10–14
185	Colegiales	16.8	16–35	17.9	18–40	16.2	18–40	16.9	16–35

Note. All times were estimated using the ArcGIS network analyst tool and verified by Google Maps.

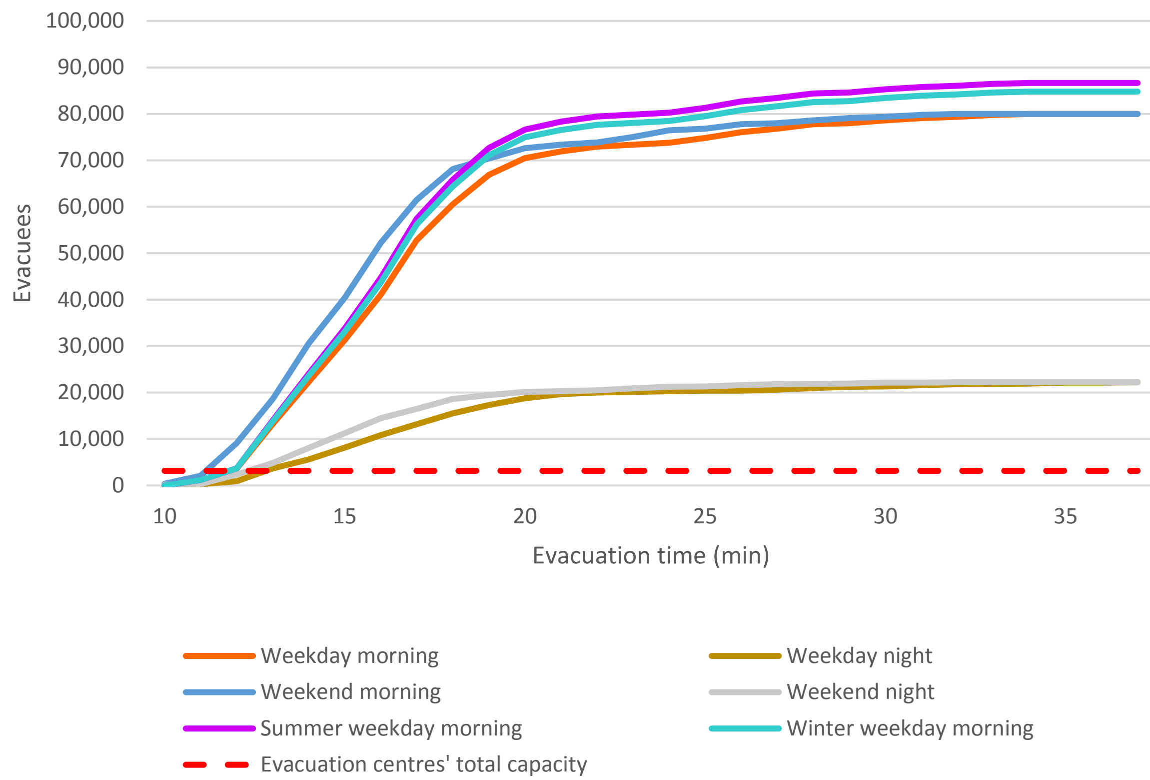

Figure 28. Cumulative number of evacuees and evacuation times of people arriving at evacuation centres in BA by vehicle.

Pedestrian evacuation. Pedestrian evacuation necessarily takes longer than vehicle evacuation; maximum travel time by foot to the nearest centre proved to be 1 hour at average walking speed (1.43 m/s, Fraser, 2014), while by vehicle, maximum travel time was only 37 minutes. Our calculations revealed that evacuation time increased on average by 12, 21 and 33 minutes when considering maximum (2.8 m/s), average (1.43 m/s) and minimum (0.88 m/s) walking speeds. Thus, in the models generated for this research, the amount of time taken by pedestrians to evacuate flood-prone areas would be 51, 34 and 25 minutes with minimum, average and maximum speeds, respectively. The longest pedestrian evacuation times at average speed were in the vicinity of Recoleta, in the east, towards bus stop number 2 (59 minutes), and in the vicinity of Nueva Pompeya, in the south, towards bus stop number 9 (50 minutes). These results are independently of the day, time or season. However, low visibility during night time or extreme weather conditions can potentially affect walking speed.

In Figures 27 and 29, the peaks in the graphs of both vehicle and pedestrian evacuation times indicate the arrival of people departing from the same census centroids, the smallest geographic unit for which statistical data is reported in national census. It is important to note that in reality, peaks should be flatter, as it is improbable that people coming from the same census centroid will depart and arrive at evacuation centres or bus stops at the same time. The number of buses required at each bus stop thus differs depending on number of evacuees arriving at any particular bus stop. The most popular stop would be bus stop number 6 (in España Park) in Barracas, where potentially, 34,010 people would need 1,031 buses within 40 minutes if walking at average speed (1.43 m/s) (Figure 29). This is in contrast to bus stop number 8 (at Luis Maria Campos) in Palermo, the stop nearest the least populated area, where up to 7,350 evacuees could be expected within 29 minutes (Figure 30).

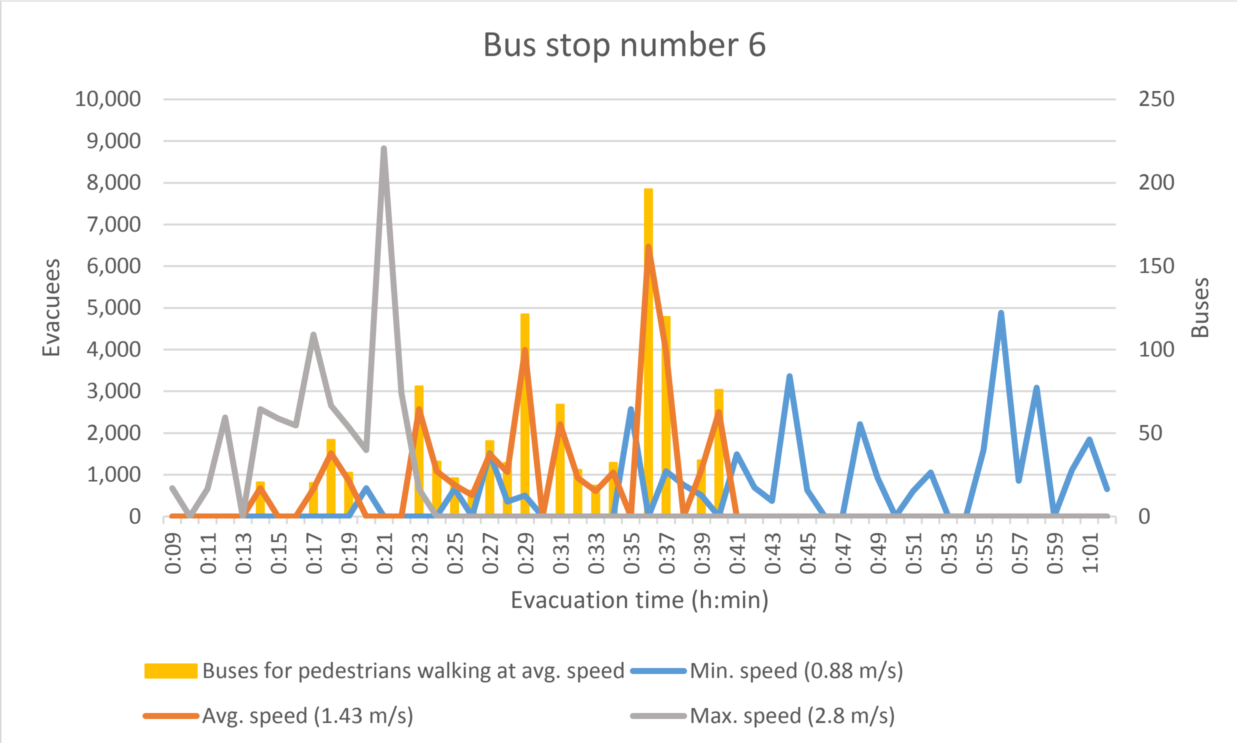

Figure 29. Number of evacuees and evacuation times of pedestrians arriving at the most popular bus stop number 6 during the day.

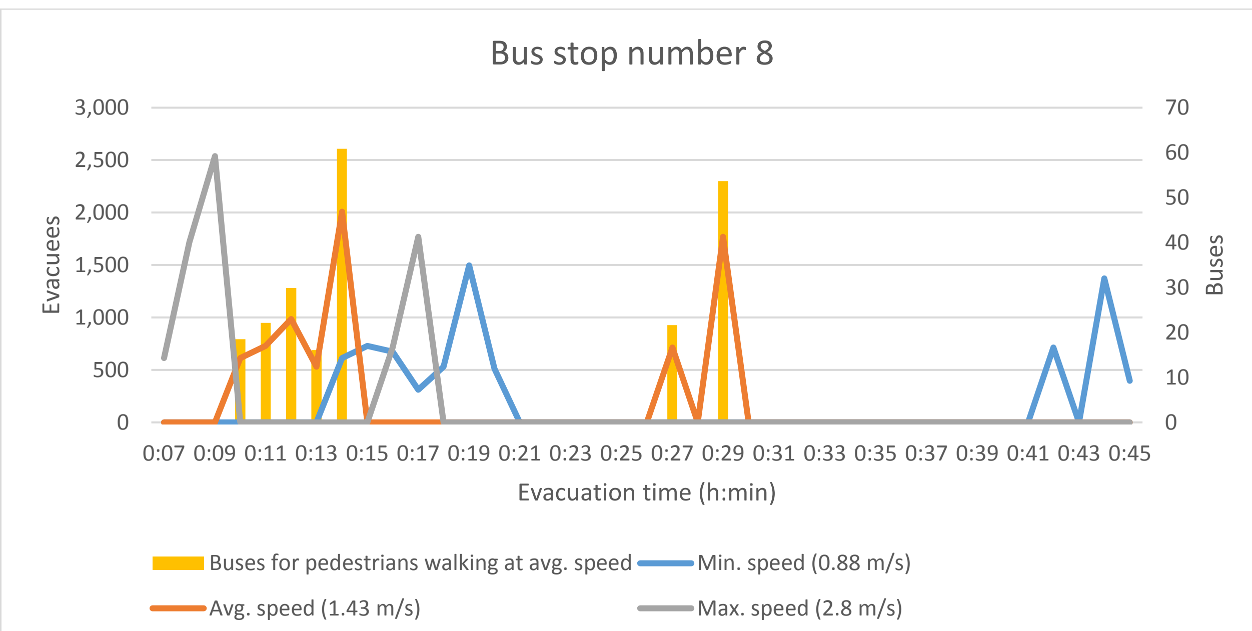

Figure 30. Number of evacuees and evacuation times of pedestrians arriving at the least popular bus stop number 8 during the day.

It was assumed the number of households in receipt of official warnings via TV, internet and mobile devices during the night are diminished because people are asleep. Consequently, people expected at bus stop numbers 6 and 8 were reduced to 9,447 and 2,042, respectively. The buses required at these stops could be further reduced, no matter what time of day, because not all evacuees will choose the same means of transport to evacuate. In the future, coordination with the Ministry of Urban Development and Transport will be necessary to guarantee bus and driver availability because currently, Civil Defence only has two buses (capacity = 23 passengers per bus) available (Buenos Aires Defensa Civil, 2016).

Post evacuation dynamics. In the models presented here, flood depths increase in each flood scenario (from 1990 to 2030, reaching their highest levels in the year 2070). Flood depths also increased with lengthening recurrence period (2, 5 and 10 years), which means more people in BA required evacuation in the latter scenarios, since evacuation probability increased with flood depth. Consequently, temporary accommodation costs rose as well. A high variability in costs is probable, as evacuees may opt to stay temporarily at the provided centres, may decide to stay with friends or family, or even in paid accommodation of diverse types.

Naturally, the longer the evacuees remained away from home, the higher the cost of temporary accommodation. Projected expenses arising during the first week in the worst-case scenario (the year 2070–10-year return flood) ranged from USD 1.03 million–USD 1.74 million, depending on the accommodation category (Figure 31). However, costs calculated for the eighth week would decrease by 20% from costs incurred during the first week, because the models assumed only 10% of original evacuees would still be unable to return to their homes by then. By the eighth week after initial evacuation it is assumed that 80% of evacuees would have returned to their homes or would have found more permanent alternative places to live, such as rental apartments or houses.

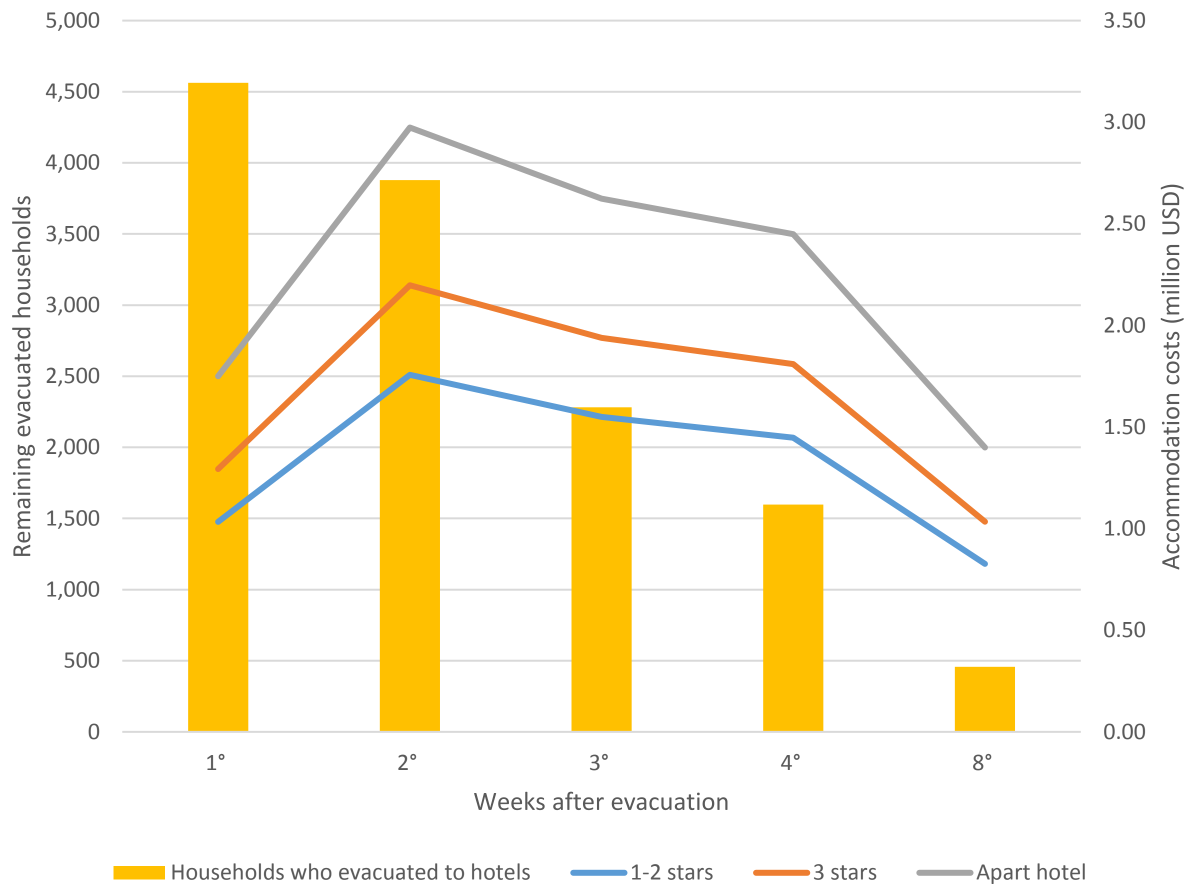

Figure 31. Temporary accommodation costs in the 2070–10-years return flood scenario, BA.

Emergency response dynamics.

Emergency response service areas. Fire station service areas were analysed for scenarios with and without flooding. Furthermore, travel distances were scaled up in flooded areas by different multiplication factors (2, 5 and 10) to simulate how inundation could affect service areas and emergency response. Fire station service areas in a scenario without floods showed that 98% of the city's population was distributed within the first two travel distance categories (0–2 and 2–5 km), while no households were located more than 8 km from fire stations (Figure 32). In all flood scenarios, emergency response effectiveness reduced gradually as the travel distance and multiplication factors increased. This result can be observed in Figure 32b–d. As service areas >8 km from facilities grew, and therefore overlapped with flood-prone areas, access became progressively more limited. Results show that Villa Soldati, Barracas, Retiro and Villa Lugano will be the most affected neighbourhoods, as 99%, 47%, 65% and 19% of their areas were exposed to inundation in the 2070 flood scenario, respectively.

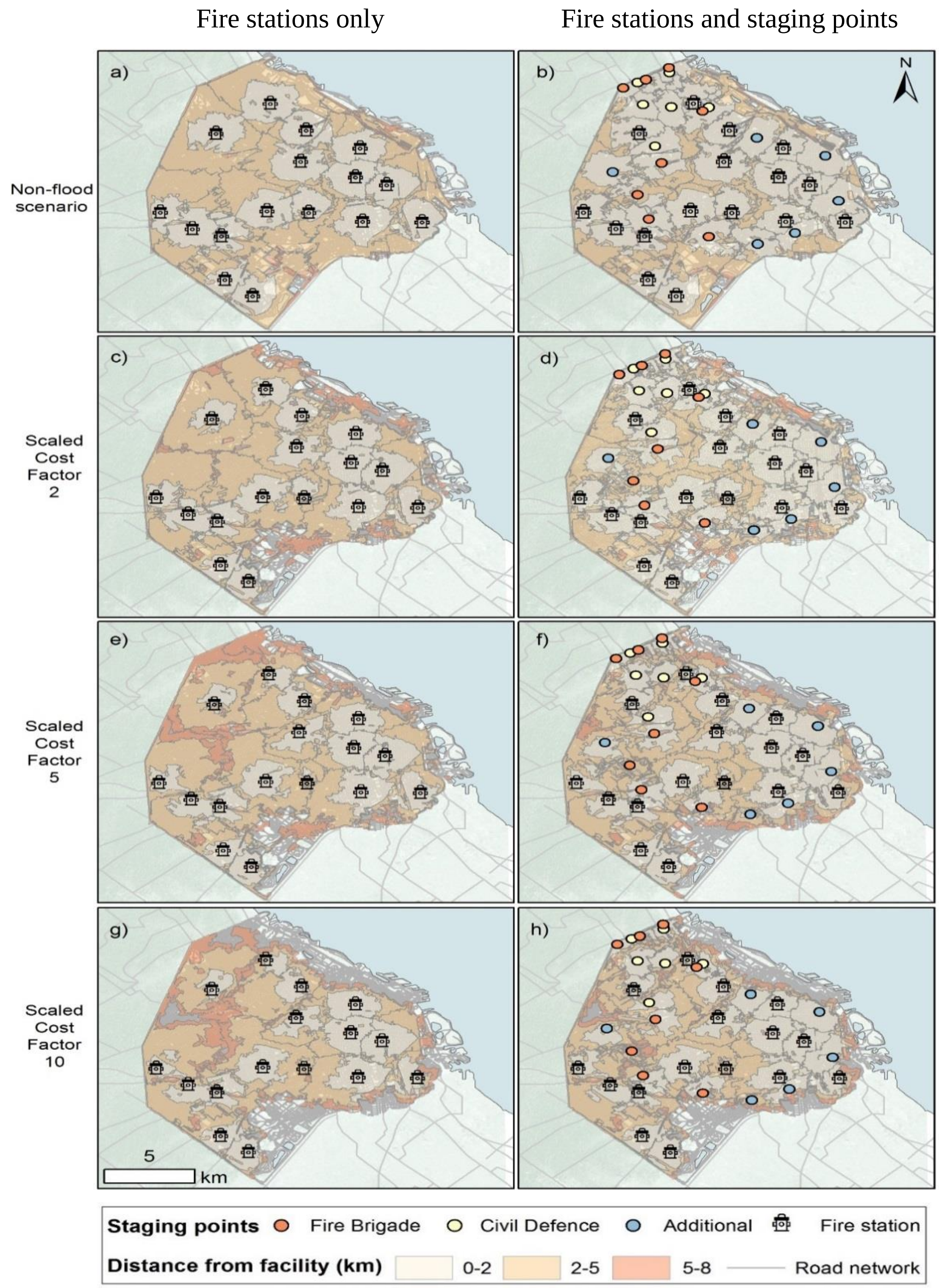

Figure 32. Fire stations and Staging point service areas in non-flood and the 2070 flood scenario with different travel distance-scaled cost factors applied.

Fire stations and staging points, sites where fire brigades and Civil Defence are located in case of meteorological warnings to offer a faster response, were also modelled together. In this case, populations located within 2 km of stations or stating points increased by 27%, while residences further than 2 km diminished by 39 % (Figure 32b). Even in flood scenarios where travel distance was scaled up, and with the addition of staging points, emergency response was improved in comparison to the response offered by fire stations independent of staging points (Figure 32c, 32e and 32g). The responses of fire brigades with the addition of staging points in flood scenarios where travel distance was scaled up by factors of 5 and 10 were quite similar (Figure 32g and 32h). Percentage population within 2, 5 and 8 km from facilities was, on average, 53%, 35% and 7%, respectively. The scaled cost of traversing flooded areas requires further investigation, however, because increases in travel distance can be site-specific. Factors such as land use, housing density and road traffic obstacles such as railroad crossings can also influence local traffic flows.

Discussion

Spatiotemporal exposure. The analyses demonstrate clearly that populations are increasingly exposed with increasing flood return interval and increasing sea-level rise scenarios. It should be noted that these estimates do not account for demographic changes, nevertheless, they serve to highlight spatial population exposure with attendant vulnerabilities. Exposed vulnerable groups, such as unsupervised children, dependent adults, the elderly, people with disabilities, electricity-dependent patients, people in slums, tourists with no local knowledge and people confined to healthcare and educational facilities need special attention from emergency managers. Knowing the location and number of vulnerable groups can help to refine vulnerability assessments and evacuation plans, and may help authorities allocate resources (e.g. portable generators or staff) accordingly.

It is concluded that if BA emergency response authorities could advise support or non-governmental organisations (NGOs) about floods, these organisations could help to spread recommendations and advice. They could also encourage individuals or families to create their own emergency plans. Such organisations could help authorities to make decisions about adults responsible for unaccompanied minors, electricity-dependent patients, elderly and disabled people. In fact, BA has the highest percentage (16%) of elderly people (over 65 years) in the country (INDEC, 2012), which directly relates to vulnerability, as the elderly often have mobility limitations and therefore must rely on others for help during evacuations (Koks et al., 2015). Furthermore, age implies previous experience with floods, which might affect the elderly population's decision to evacuate, or their preferred routes. The highest numbers of elderly living in flood hazard areas are located in the north and central east parts of the city, in the districts of Nuñez, Belgrano, Palermo and Recoleta.

Tourists are also a vulnerable group because they might not speak the local language, know the evacuation routes or how to find help. Identifying tourist hot spots, such as areas with a high concentration of tourist attractions in Puerto Madero, Recoleta, Palermo and the San Telmo neighbourhoods, and training local tourism industry staff, could complement other emergency planning efforts. Providing information about hazards has proved to be useful to tourist operators during past emergency events, rather than negatively impacting the industry (New Zealand Civil Defence, 2008).

People living in slums, concentrated in the south, are also vulnerable. Access to these places is difficult because roads are not wide enough for fire trucks, and slum inhabitants are sometimes reluctant to allow governmental agencies to enter their neighbourhoods. Therefore, Civil Defence-trained leaders are needed in slums to empower the community during the evacuation of these informal settlements (C.A. Alvarez, Undersecretariat of Emergencies, personal communication, January 10, 2017). Areas close to train lines or train stations are also difficult to access, because vehicles have to avoid them and find the closest level crossing.

Developing site-specific evacuation plans guarantees the availability of transport for slums, healthcare and educational facilities requiring extra assistance (New Zealand Civil Defence, 2008). Site- and context-specific plans also enable large groups to be evacuated with less difficulty. Alerting special needs groups and vulnerable populations about flood evacuations as soon as possible can shorten evacuation times and reduce stress to evacuees. It is clear that Civil Defence partnerships with support groups, transport authorities, health officials, tourist operators and educational agencies are fundamental for an effective emergency response in BA. The *BA Emergency Management Plan*, set up in 2009, provides the legal framework for coordinating activities within agencies, but practical coordination and interconnectedness requires strengthening.

Future exposure of population in flood-prone areas might increase in future flood scenarios if population growth is considered. However, based on local statistics BA total population starts to decrease after the year 2031, probably due to aging population (Buenos Aires Ciudad, 2016).

Evacuation analysis. Evacuations can occur during working or non-working hours. Therefore, Civil Defence needs to inform the BA population about the location of evacuation centres by methods people use to communicate on a daily basis, such as social or print media, community trainings and signage. Use of multiple media would facilitate awareness and would encourage people to plan their own evacuation routes, either from their residences or workplaces. People should also be advised to evacuate with a group who live or work nearby, and to consider alternative routes and meeting places if their preferred route is unpassable for any reason (New Zealand Civil Defence, n.d.).

Results suggest that facilities and logistics issues should be addressed in the evacuation planning phase. Practical aspects such as signage, staff rosters, on-site security, transport options, free phone lines between evacuation centres to help reunite family members, shuttle services to key facilities (e.g., banks and governmental agencies) and alternative waste management are better organised before flooding occurs. Access to healthcare, either existing facilities, or specially set up mobile clinics or health posts, is especially critical, and is therefore best organised pre flood.

Approximations presented here of households requiring evacuation seem to overestimate the number of evacuees when compared to actual numbers of evacuees, as reported in newspapers ("Storm in Buenos Aires," 2012; "Almost 50 deaths", 2013; "The April storm," 2013). Unfortunately, no official statistics quantifying evacuees from past BA flood events exist. On the other hand, unofficial reports might be inaccurate because no official system tracking evacuees exists in Argentina either, and areas flooded in the past have been smaller than those predicted in the scenarios evaluated in this research. Therefore, post-event surveys are an essential tool for Civil Defence authorities. Such surveys would enable them to learn more about how evacuation may actually work in local BA areas.

Estimates of potential evacuees generated in this research may be further reduced by the fear of looting ("The images," 2013;“Robbery," 2013), which makes people reluctant to leave their homes. The number of evacuees can also vary due to perceived risks. Prior surveys developed by BA Civil Defence have revealed that in some areas of the city, people underestimated flood risk and did not consider themselves vulnerable to floods, despite devastating flood events they had already experienced, and despite often medium to high educational levels (E. Ferreti, Civil Defence, personal communication, December 26, 2016). Another survey showed that two-thirds of respondents did not feel exposed to flood hazards; respondents also felt that if a flood event did take place, its damage would be very slight, and that existing infrastructure would help to reduce the risk (Barachetti, 2016). As many as 90% of respondents put their faith in existing infrastructure (Barachetti, 2016).

The perception of individuals that flooding in BA is low risk is directly related with a recognised unrealistic optimism bias, that means people consider themselves as less vulnerable and more skilful than others (Burger & Palmer, 1992). Thus, perceived risk is lowered, and mitigation measures, or even evacuation options, might be discounted. A Swedish study also found a weak relationship between background factors, such as educational level, and risk perception (Sjoberg, 2000).

Media can also influence people's perceptions of risk and consequent behaviours. For instance, in BA, media reports can make people focus on other hazards that jeopardise life, such as crime, car accidents or economic instability, and because flooding does not feature daily in media reports, people may neglect flood risk. The way information is presented, especially risk and probability issues, can have a significant influence on how people interpret risk and assess their vulnerability. People often assume low probability risks to be similar to zero (Stone, Yates, & Parker, 1994), or they may unilaterally reduce probabilities of a large or small number to a level familiar to them, avoiding any distinctions (Stone et al., 1994).

Community debates or forums about risk, organised by official agencies, are a powerful tool to make people confront their perceptions about their own vulnerability and the preventive measures they need to put into place (Barachetti, 2016; Paton, Smith, Daly, & Johnston, 2008). In this way, the community is also able to participate during the decision-making process and with the guidance of scientists and authorities. For example, they should be able to get involved in the determination of river height indicators that can trigger actions such as dissemination of evacuation warnings, or evacuation itself. Community engagement also allows agencies to get to know people's perceptions and how they might interpret future risk management measures or evacuation warnings (Paton et al., 2008). Moreover, governmental agencies can build trust with the community during these meetings. Then, people will be more likely to believe in them and the information they deliver, and may even use it for self-preparedness, instead of transferring the risk to others in society.

Vehicle evacuation. Congestion in BA during evacuations can be reduced with a well-planned traffic management system. Such a system might use traffic control staff, traffic lights and/or contraflow, the altering of the normal flow of traffic in the opposing direction. Good traffic management may facilitate evacuation by stages (e.g., by neighbourhood). Keeping people informed about weather and road network conditions is also paramount, as such information can reduce road injuries and fatalities. For instance, the Christchurch City Council provides maps showing roads that are closed, restricted by high tide, or where caution is advised, to residents, so people can plan their evacuation routes (Christchurch City Council, n.d.). This initiative highlights the importance of updating weather and road network databases frequently, and of linking them to hazard management and flood damage databases.

The models generated in this study showed that BA evacuation centres can reach their capacity quite quickly, within around 12 minutes of evacuation time by vehicle. Once capacity is reached, in reality evacuees must be redirected to the Pomar and Costa Rica centres, outside the flood-prone areas, even if this implies travelling longer distances. The Parque M. Belgrano and Parque Patricios centres, both in the flood-prone areas, can potentially host evacuees if they are not inundated. Even if evacuees are redirected to other existing evacuation centres, total existing capacity is not enough, because it only represents 0.11% of BA's total population and 3% of total number of evacuees for the modelled scenario. Especially during the summer, when there is a large influx of visitors, including international tourists, existing centres would be stretched beyond capacity.

Pedestrian evacuation. Results from this study showed that emergency managers should use information about evacuation times to focus their resources on the evacuation of areas with the longest evacuation times, or increase the number of buses, as Civil Defence only has two buses (capacity = 23 passengers). The capacity of bus stops has not been addressed, but it is a critical factor authorities could use to their advantage to avoid overcrowding at evacuation centres, especially in the mornings, when 90% of flood-exposed households are expected to receive an evacuation warning. These results indicated that more bus stops are needed in BA to reduce congestion. In saying this, available resources should be reviewed with the local city council first.

Traffic logistics for both pedestrian and vehicle evacuation should be considered by BA authorities. For instance, the allocation of parking spaces and the design of informative and understandable signals to direct evacuees before and after their arrival at evacuation centres or bus stops before a flood occurs is important, as emergency managers might not be able to provide help and directions to larger groups. Furthermore, registering evacuees by gathering contact details, information about health conditions and ultimate destination is a highly valuable practice. Keeping such records may help authorities reunite family members and may also improve emergency management, especially in the return phase or in future events. Self-evacuees should be encouraged to register via toll-free 0800 phone lines, as per the New Zealand Red Cross system (New Zealand Civil Defence, 2008).

In addition to evacuation planning, the return of evacuees to their homes should be planned for. Planning the return phase in BA should include several aspects, such as hazard level and probability of flood reoccurrence in formerly evacuated areas, buildings infrastructure safety and habitability, level of infrastructure and utility serviceability, hygiene, security of the general area and road networks, and intactness of transport facilities. People who previously evacuated by private vehicle should be encouraged to return home in stages, while transport facilities should be arranged for pedestrians.

Recovery centres, currently non-existent in BA, should be located separately from evacuation centres to reduce logistics issues if possible. Evacuation centres operate for a period of time as people gradually find other temporary accommodation or return home, whereas recovery centres may operate long-term, even when evacuees have returned to their homes, by promoting the emotional, social and physical well-being of people, or by helping them to access resources for rehabilitation and restoration.

Post evacuation dynamics. The percentage of households who evacuate to centres, and the time they remain in them, is useful information for the management of such centres and supplies. The costs of and time spent in alternative accommodation by evacuated households are important for the estimation of damage costs incurred either by the evacuees, or by the authorities, and for the calculation of insurance or governmental reimbursement of these expenses.

Additional costs caused by flooded properties and evacuation can include food, travelling and loss of earnings, among others. For instance, people may incur additional expenses such as cleaning products, clothing, bedding, furniture and medical supplies. Food can be also more expensive because evacuees might not have the necessary facilities to cook, and therefore, they will need to buy already prepared meals. Travelling can become more costly, since commuting from temporary or alternative accommodation to the flooded residence, work or school can imply longer distances. Affected households might also need to take time off work to clean, dry and repair their properties, which can be measured as a loss of earnings. To avoid unnecessary accommodation costs, an assessment of residential building damage should be conducted as soon as practicable to determine habitability. A conservative assessment should be avoided if the displacement of people is the result, but at the same time, occupants should not be exposed to risks from unsafe buildings. The property assessment can be structured in two phases, as done by British Columbia Housing (BC Housing, 2017) in Canada, and New Zealand's Building Performance branch of the Ministry of Business, Innovation and Employment (MBIE, 2014). First, a rapid damage assessment (10–30 min per building) is performed to identify structural and non-structural hazards that can make the building, or part of it, unsafe. Once the safety of the building's occupants is guaranteed, a detailed assessment (1–4 h per building) is performed to ascertain necessary repairs and resources (BC Housing, 2017; MBIE, 2014). Properties in BA can be assessed similarly, with the use of an assessment form for residential or complex residential buildings (Appendix C), and all non-residential buildings. All buildings can be classified with the following (water-proof) placards on visible entranceways:

- "Can be used" or "inspected". There are no unsafe conditions or structural damage, but minor repairs may be needed. The owner or occupant can take the placard down.
- "Restricted use" or "restricted access". There is a hazardous condition that restricts the entry or use of the structure. For instance, people might be prohibited from entering or using specific areas of the building, or might be allowed brief entry to retrieve their belongings. Alternatively, they may be directed not to use flooded or damaged services, devices, appliances or fixtures until re-inspection. Placards can be removed by a licensed contractor or the building authority.
- "Unsafe" or "entry prohibited". The property is unsafe for occupancy or entry. Placards can be only removed by the building authority. If buildings are classified as unsafe, then evacuation should be ordered. Implications of such an evaluation should be explained to occupants to make the process more transparent and to promote people's cooperation during evacuation. The security of the buildings and their contents should be ensured while occupants are away.

Emergency response dynamics.

Emergency response service areas. The analysis of service areas highlighted the importance of reviewing the approach currently used to define fire station service areas in BA. In this analysis, travel distance was considered as an alternative to using city authority boundaries to demarcate service areas. The relocation of existing staging points outside the hazard areas, and the addition of new staging points, would improve the efficiency of BA's emergency response, especially in floods. Although political relationships were unable to be addressed in this research, we also believe the creation of bonds between emergency response authorities and the community is critical, especially in slums where self-evacuation is likely.

Proposed alternative emergency response service areas. To meet the ultimate goal of this research, which is to improve flood emergency response in BA, an alternative emergency response scenario for the city was developed by analysing fire station service areas and existing staging points, which are sites where eight fire brigades and six Civil Defence are located. These facilities are in place in case of meteorological warnings, and enable authorities to offer a faster response. In this analysis relocating some staging points to sites outside flood-prone areas and to higher ground was explored. Even though there are several staging points in the Saavedra neighbourhood to the north, it was decided to not remove them. Instead, it is assumed the city council located them strategically because of the high vulnerability and recurrent inundation of the relatively new DOT Baires shopping mall, which has already motivated neighbours to make several requests for emergency assistance to the government ("Neighbours of Mitre,"2012)

To model an improved flood emergency response in BA, six additional staging points were located in areas where no staging points currently exist (Figure 32b and Table 15). The aim was to reduce travel distance for flood evacuees and emergency response personnel. It was decided not to contemplate new fire stations, because they are expensive and time-consuming projects that include building, buying or renovating infrastructure. Staging points imply little new infrastructure, but they do involve additional equipment and human resources. Therefore, we limited additional hypothetical staging points to six.

Table 15

Analysis of emergency response facility service areas, BA

Facilities included in the model	Non-flood scenario	Flood scenario and travel distance-multiplication factors
16 fire stations	Yes	2, 5, 10
16 fire stations + 20 staging points (8 fire brigades, 6 civil defence evacuation centres, 6 additional)	Yes	2, 5, 10

Note. Staging points are sites where fire brigades and Civil Defence locate when a warning is issued to offer a faster response.

A better emergency response was shown when fire station service areas were analysed together with staging points (existing and additional) (Figure 32b, 32d, 32f and 32h), because more residences fell within a 2 km radius of facilities. The addition of a hypothetical staging point in Villa Devoto, a neighbourhood in the western city centre that tends to waterlog, greatly improved emergency response coverage. No staging points currently exist in this vulnerable area, and the closest fire station is approximately 3.2 km away. In Villa Devoto, no one lives within a 2 km distance of fire stations (Figure 32a), and after a staging point was added to the analysis, it was found that 42,905 Villa Devoto locals would be able to receive a quick response. Nueva Pompeya, located in the river flood-prone area in the south, also benefited from the addition of a staging point (Figure 32b). The local population that then fell within a 2 km radius from facilities increased by 384%, a substantial improvement.

A proposal for additional evacuation centres and safe areas. In order to further improve BA's emergency response capacity and the welfare of flood-exposed populations, a 100 m safety boundary was delineated around flood-prone areas to consider the flood model inaccuracies and guarantee the evacuees safety. The buffer tool in ArcGIS to classify existing evacuation centres and to identify potential sites for additional centres (Figure 33) based on the safety of the location. The use of the buffer tool assured the greatest resemblance between the shape of the safety boundary and that of the actual flood-prone areas (Alabdouli, 2015).

Alabdouli (2015) used the ArcGIS buffer tool to create a tsunami shadow evacuation zone. Unlike in tsunami evacuations, however, terrain elevation is not the main factor guaranteeing safety during flood events, because, occasionally, areas higher than 15 m may become waterlogged due to poor drainage capacity and shallow gradients common to BA landscapes. This complexity motivated us to consider all factors: elevation, areas prone to flooding by the La Plata River and high-intensity rainfall events.

In this project, existing evacuation centres were classified first by their location (inside or outside the flood-prone area, and travel distance), and secondly, by their capacity to host evacuees (Table 16). Given that existing evacuation have a total capacity of 3,159 people (0.11% of BA's total population, and 3% of total number of evacuees for the 2070 flood scenario), and that some of them are located in areas affected by floods (such as Parque M. Belgrano and Parque Patricios), places to build additional evacuation centres and to establish new safe areas were identified. Having additional safe areas and evacuation centres in more suitable locations in BA would reduce evacuation times and avoid overcrowding at existing centres. The new safe areas and evacuation centres we propose are situated in easy-access locations outside hazard areas, but are still close enough to flood-prone neighbourhoods to facilitate evacuation. In addition, the placement of the new sites we propose allows for fluctuating use during the day, because people can make use of facilities during the day and sleep at nearby relatives and friends' places located in contiguous, flood-safe neighbourhoods (Australian Red Cross, 2013).

Community sports centres and sports clubs were also identified as potential evacuation centres, which were preferred over community sports centres, because the latter ones are generally smaller, and might not be able to accommodate big groups of evacuees. Schools were not considered as an alternative in this study, because class disruptions would be detrimental to students. Use of schools is also non-compliant with the *BA Emergency Management Plan*, which prioritises sports clubs (GCABA, 2009).

Sports clubs can be used as evacuation centres, either for day or overnight stays, depending on their facilities. An average area of 1 m^2 per person should be used to calculate centres' sleeping capacities, as recommended by FEMA (2008), and a larger area is needed for people with service dogs, such as seeing-eye dogs. Special consideration should be given to sports clubs that are privately owned, as owners might not be willing to offer their facilities. Furthermore, it should be noted that sports clubs located in the north (e.g., Club Atletico Platense, Club Racing de Villa del Parque and the Asociación Atletica Argentinos Juniors) might end up isolated if flooded areas extend in severe flood events, which might hinder further evacuation or delivery of supplies.

In this research, it was also recognised parks as safe areas in a bid to improve emergency response options for BA. Parks were chosen as safe areas because they are large, uncluttered areas where emergency management agencies can set up temporary facilities, such as chemical toilets, information kiosks, medical clinics, food and sanitation distribution points, and animal shelters. As part of planning, rules governing the transportation of animals and veterinary care facilities should be established to reduce distress to animals and their owners, similar the U.S. *Pets Evacuation and Transportation Standards Act* (2006).

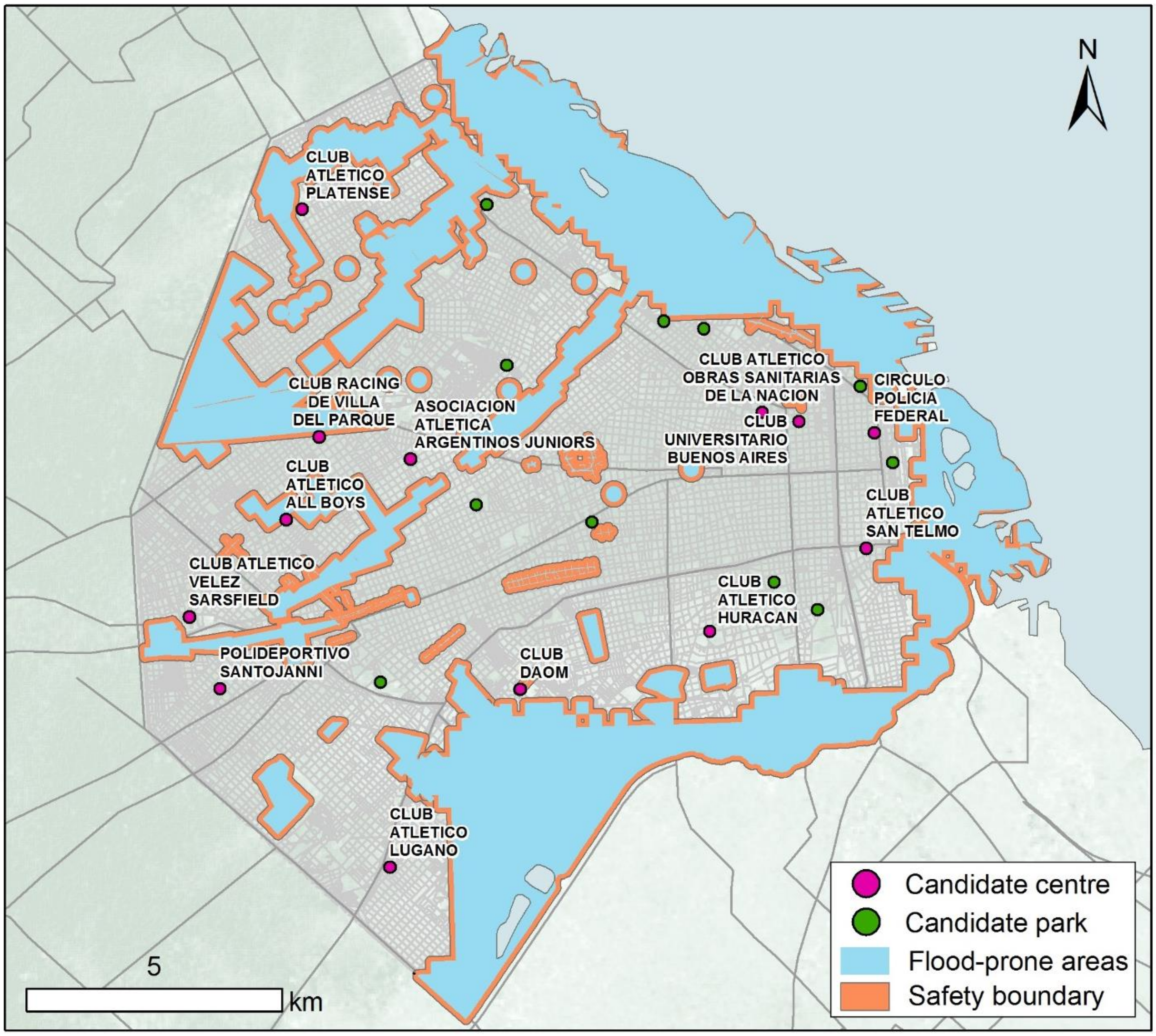

Figure 33. Safety boundary (100 m), evacuation centres and parks proposed for use as safe zones in the event of a year 2070–10-year return flood in BA.

Note. A 100 m safety boundary around flood-prone areas was set to consider the flood model inaccuracies and guarantee the evacuees safety.

Table 16

Classification of existing evacuation centres based on location and capacity

Evacuation centre	Capacity	Rank	Observation
Chacabuco	819	1	Preferred
Avellaneda	444	2	Preferred
Colegiales	255	3	Preferred
Martin Fierro	240	4	Preferred
Dorrego	179	5	Preferred
Pereyra	91	6	Preferred
Costa Rica	380	7	Preferred
Pomar	211	8	Preferred
M. Belgrano (KDT)	378	9	Potential alternative, if not flooded
Patricios	162	10	Potential alternative, if not flooded
Total	3,159		

Note. M. Belgrano (KDT) stands for Manuel Belgrano (Kilometre, Distance, Time). Evacuation centres were ranked first by their location (inside or outside the flood-prone area, and travel distance), and secondly, by their capacity to host evacuees.

Some of the difficulties that BA emergency managers face, in addition to the low capacity at evacuation centres, include a lack of staff and/or economic resources, and lack of cooperation from governmental agencies, which are sometimes reluctant to share information (E.

Ferreti, personal communication, December 26, 2016). The current inadequate investment in basic infrastructure lifelines and critical utilities does not help in reducing service disruptions during floods, either. Other aspects that still need improvement are early warning systems, weather forecasting and radar interference. Radar and hydrometeorological monitoring stations are currently being acquired to reduce these issues. Capacity, finances and technology transfer were also identified as limiting factors in the Sendai Progress Report (*Sendai Framework Data Readiness Review–Argentina*, 2017) (UNISDR, 2017). The lack of georeferenced data and tools to assess risk exposure have also been formally recognised (Barachetti, 2016). Getting access to resources from other agencies or cities may also be a practical alternative authorities could consider when addressing deficiencies.

Other strategies that might help to improve emergency response are mobile applications, which have proved to be highly useful for both emergency managers and flood-affected populations (Houston et al., 2015). For instance, emergency managers can benefit from mobile phone apps that can be used to distribute information widely, or to trigger local alerts and warnings, gather volunteers pre- or post-occurrence and to collect information about disaster effects. Populations can take ownership of mobile apps as well, by adding risk maps or evacuation routes, reporting a hazard nearby, learning about preparedness or by receiving recovery information post event. People can also use apps to engage in crowdfunding, crowdsourced hazard monitoring, sending "I am safe" messages to relatives and friends and monitoring more than one location according to the user's location, or the location of family and friends (Tan et al., 2016). Fluent, transparent communications between emergency managers and affected communities prior to a hazardous event helps to decrease information demand during emergencies, and avoids the effects misinformation spread through unofficial channels

(New Zealand Civil Defence, 2008). Overall, a well-planned evacuation strategy will allow a more organised evacuation in BA, and an efficient use and distribution of resources. Planning and modelling will also help all stakeholders to avoid last-minute decisions, like those taken during hurricane Harvey in Houston, Texas, where furniture stores were converted into shelters (Wrights, 2017).

Research Limitations and Potential Improvements

The limitations of the Chapter 3 analysis, and potential improvements, are summarised in Table 17. Model overestimations, underestimations and neutral estimations are also indicated in Table 17.

Table 17

Research Limitations and Improvements

Assumptions and limitations	**Implications for model**			**Potential improvements**
	(-)	**(+)**	**(+/-)**	
Delimitation of exposed population				
Flood model is low resolution (73 × 73 m cells) and is set at broad flood depth increments (1 m)				Use of a high-resolution DEM and more detailed georeferenced census data (e.g., age, disabilities, educational level, income level, number of vehicles per household), whenever data become available, to better estimate the exposed population and determine their demographic characteristics
Evacuation probability was developed for U.K. conditions. It considers evacuations based on flood depth				Development of a survey to describe people's behaviour during a flood event will help to identify the possible number of evacuees, the best evacuation routes, destinations, mean of transport and to understand the relationship between demographic variables and evacuation decisions. This information should be also be recorded for future flood events to check if people's responses are different from surveys results Consider infrastructure lifeline disruption and behavioural factors that might influence evacuation. Engage with experts who operate lifelines and also professionals who have a good understanding of the Argentinean culture
Evacuation costs were only measured in terms of accommodation costs				Food, commuting, medical, and repair expenses should be included in cost evaluations

Evacuation model				
Lack of infrastructural data regarding proposed evacuation centres and resources available to establish new staging points and safe areas.				Evaluate together with emergency managers the feasibility of using proposed sites and classified them in terms of available facilities, repairments needed, viability or current necessity.
Evacuees included in the same census meshblock depart at the same time from the same origin (census centroid) instead of independent locations.				Use of tax-lot level land use data. Congestion might ease throughout time since evacuees will not depart at the same time in reality.
Similar characteristics were assigned to all evacuees like walking speed, mean of transport, and initial delay time per evacuee.				A detailed census dataset with information about subgroups, (e.g. children, elderly, disabled people, etc.) and number of vehicles per household would be could be used to estimate the ratio of people with similar walking speed or evacuating by car. Bus demand might be reduced as not all the evacuees will choose the same mean of transport to evacuate. Bus drivers' compliance is assumed to be 100% during evacuation and should be guaranteed by transport agencies.

The following factors were not considered: • fatigue or walking speed variations throughout time • influence of travelling with belongings • evacuation path re-evaluation once the evacuation has started • congestion caused by evacuees departing at the same time, which may be more significant than normal rush hour				Use of agent-based modelling approaches that consider individual differences in physical fitness and impacts of carrying possessions can be used to refine analysis. Existing CASPER evacuation modelling in ArcGIS would be useful to account for evacuation path re-evaluation and road capacity saturation.
Emergency response service areas				
Non-updated or detailed road network. Travel time-scaled factors of elements (flooded area, fallen tree, accidents, a downed electrical line, road work) interfering with traffic were assumed				Use of an updated and detailed road network dataset (describing road speed limits, classes and widths, hierarchy, number of lanes, etc.) could be used to establish fire brigade service areas. Travel time- and distance-scaled factors should be recorded in future flood events to evaluate how they influence emergency response and evacuation. Updates of the evacuation model with live data (e.g., flood depth, congestion, elements interfering with traffic) should be performed after each flood event.

Note. (-) refers to underestimates, (+) to overestimates, and (+/-) to neutral estimations for flood damage in BA.

Conclusions

Although evacuation requirements are directly proportional to flood depth, even shallow flood waters (0–1 m) can have a significant influence on population displacement and evacuation costs. Therefore, shallow floods should not be underestimated, and because utilities can be disrupted in BA even in shallow floods, potential evacuation in the case of a 0–1 m flood should be considered by authorities.

Evacuation models generated for this thesis showed that bus stops could become overcrowded and that evacuation centres may reach their capacity in a short period of time. These results highlight the need for coordination between emergency response agencies, such as Civil Defence and the Ministry of Transport, to increase the number of bus stops and the capacity of evacuation centres. Existing centres can only accommodate 0.11% of BA's total population (3% of the total number of potential evacuees in the 2070 scenario). Moreover, evacuation of vulnerable groups and neighbourhoods with the longest routes of travel to evacuation centres, especially during weekdays and peak traffic hours (7–8 a.m. and 6–7 p.m.) requires special attention. There is also a need to calibrate and validate the BA evacuation model with historic scenarios, and to adjust flood model parameters to suit local conditions.

Despite recent improvements in BA's urban and emergency planning frameworks and institutional arrangements, which have been introduced in the last two decades, the emergency response capacity of BA remains limited due to deficient or lacking resources, tools and staff. Therefore, institutions should promote self-efficacy, that is, authorities should aim to empower the population by increasing their perceived capacity to respond to hazards (Paton et al., 2008; Rakow et al., 2015). In other words, the key to improving emergency response is to develop city communities' intrinsic resilience. This can be achieved by encouraging communities to participate in response-to-scenario events, encouraging families to stockpile vital consumables, and assisting citizens to design private or household-level flood response plans compatible with evacuation routes, among other strategies. This would relieve some burden on the government during the response phase, but would also translate into people being able to recover from disasters at a faster rate.

In addition to building intrinsic resilience, other ways to improve emergency response capacity include establishing fire station service areas based on travel distance, by relocating stations themselves, or by adding staging points. A review of existing staging points is also necessary, as there many located in the north of BA, and they only service areas that tend to waterlog in high-intensity rainfall. Areas that flood from river overflows have no staging points. The staging points, safe areas, evacuation centres and routes proposed herein are meant to strengthen the emergency response. However, these proposals should be examined in partnership with the local city council to evaluate their usefulness and in light of available combined resources.

In future research, evacuation thresholds, emergency facilities, potential evacuees, evacuation times and increases in travel times required for traversing flooded areas could be further investigated to improve emergency response. A better understanding of the BA population's behavioural patterns is also required to account for the different ethnic groups that live in the city (indigenous, Latin American, Asian, European). Developing a survey to evaluate people's behaviours during a flood event will help in identifying the possible number of evacuees and in designing evacuation routes people will actually know and use. The survey could also be used to to understand the relationship between demographic variables and evacuation decisions.

Chapter 4

Conclusions and Recommendations

This thesis contributes to a better understanding of flood impacts and the influence of future projected sea level rises on the city of BA. Herein, quantified flood damage to buildings and infrastructure lifelines have been quantified under current conditions. Flood impacts were also projected resulting from sea-level rises predicted to occur over the 21st Century (Chapter 2). The assessment of flood impacts allows a clearer understanding of how emergency responses can be hindered, and where evacuation might be needed, due either to flooding or to infrastructure disruption. To identify the factors that increased flood spatial vulnerability in BA the most, the influences of land price, housing density and urban plans on flood impacts were investigated.

To determine if the city's current emergency plan undermines emergency response capacity, fire station service areas and service populations were further evaluated (Chapter 3). The location of the populations exposed to floods and their demographic characteristics were also considered in the analysis. The aim was to characterise them, and later on, to propose evacuation routes, staging points, additional evacuation centres and flood mitigation measures based on social characteristics.

Below is presented a summary of the conclusions drawn and recommendations made in each chapter. Both conclusions and recommendations will not only contribute to the work that the national and BA city governments are doing to improve flood management, but will also inform the National Platform for Disaster Risk Reduction (DRR) (Cancillería Argentina [Argentinian Chancellery], 2007) and the *BA Action Plan in the Face of Climate Change 2020* (GCABA, 2015a). These documents are currently being formulated with contributions from local BA emergency response managers. Chapters 2 and 3 provided many relevant insights about flood management and mitigation in BA, which are summarised in the following sections.

Conclusions

Flood impacts. First, exposed lifelines and utilities were located and mapped for the purposes of informing future flood mitigation and emergency response in BA. These maps can now be used to inform emergency managers about potential alternative evacuation routes or resources they may need in certain flood scenarios. Importantly, this research illustrated that infrastructure lifeline disruption can have indirect effects in areas outside BA. Therefore, the overall area that risk managers need to focus their mitigation efforts on should be enlarged.

Results from this research also showed that the highest flood damage costs are always sustained by the commercial sector. Residential and commercial building damage was evenly distributed throughout flood-prone areas, and was not concentrated in a single neighbourhood. This result is in direct contrast to the lack of spread in industrial damage, because industrial areas are concentrated in the south of BA. Of note is the fact that high-density housing (i.e., slums) and high-value residential areas (i.e., Puerto Madero) are likely to suffer the highest residential sector losses.

This study illustrates clearly that substantial building damage can be caused by relatively minor floods in BA (e.g., 2- and 5-year events), and a considerable increase in financial losses can occur as the severity of flooding increases (e.g., in a 10-year event). It also shows that losses are exacerbated by future projected sea level rises. Fortunately, recent updates to BA's legal framework and institutional arrangements have improved local flood mitigation, which may reduce losses. However, more enforcement of regulations and restrictions, more active coordination between governmental agencies and more incentives for individuals taking flood mitigation measures into their own hands are required to extend the impact of existing regulations.

Emergency response. Even shallow flood waters can have a significant influence on population displacement, evacuation costs and service disruptions. Bus stops can become overcrowded quickly, and models showed that existing evacuation centres will reach their capacity in a short period time. Better coordination with transport agencies and sports centres in BA, which are used as evacuation centres, is required to guarantee bus driver compliance during evacuation and to increase emergency response capacity.

Estimations of evacuees, and time required to reach bus stops and evacuation centres, have been made in this study. Potential evacuation routes and neighbourhoods requiring longer times to evacuate were also identified. This information can now be used to assist emergency managers in BA to prioritise neighbourhoods for evacuation and to allocate resources in a meaningful, efficient way. Specifically, better management of bus drivers, meals, beds and waste disposal can be realised by using the new information contained in this report.

The socio-economic characterisation of flood-exposed populations in BA allows authorities to identify and locate vulnerable groups requiring assistance or more time for evacuation. In BA, the high percentage of elderly people, concentrated in the northern and central east regions of BA, are one such group. The need for specific evacuation plans was also identified for the many areas where limited road access will hamper rescue efforts, such as in slums to the south of BA.

Furthermore, there is great potential for improving emergency response by re-establishing or establishing new fire stations and staging point service areas based on travel distance, rather than local territorial authority boundaries. To enhance such a change in approach, provided here for the BA authorities are specific options for new safe areas. These proposals should go a long way towards overcoming barriers such as lack of data, resources, data sharing and coordination, which undermine efficiency. In addition, the newly introduced legislation should support the recommendations and proposals contained herein.

Recommendations

Flood impacts. Flood mitigation needs to be tailored to social characteristics (Kooks et al., 2015). For instance, elderly people, concentrated in the northeast of BA, may require more time to evacuate; hence, improving flood control infrastructure in the northeast may be a more suitable option for these areas than expecting the elderly individual to put their own mitigation measures into place. In contrast, subsidies to improve residential housing by installing water-resistant materials, or insurance vouchers, can be useful for aiding low-income residents in the south of BA.

In view of the uncertainties regarding climate change, and the threshold that insurance companies use to determine when they will not insure properties, it is necessary to enhance community resilience in BA. Focusing only on flood recurrence, or the rate of sea level rise, will not work for BA (Stephens, 2015). For example, by promoting systems redundancy, responsiveness, flexibility, safe failure, capacity to learn, better building practices and learning from disasters, authorities can teach people to face climate change-related hazards (e.g. sea level rise) (Revi et al., 2014). Implementing such a dynamic adaptive policy pathway (Haasnoot et al., 2013) will allow BA authorities to put effective, comprehensive flood mitigation measures into practice (as detailed in Chapter 2).

Attention should also be paid to the sustainability of current land use practices in the BA region (Saunders, 2010). Restrictions on land development, or swapping to low-damage land uses in hazard areas, might be necessary. Low-impact, flood-resistant examples could include playgrounds, recreational areas and carparks. In addition, guaranteeing maximum possible functionality of lifelines and utilities during and after an emergency, as they are critical for sustaining livelihoods, is also necessary (Civil Defence Emergency Management Act 2002, S60). Options for BA may also include decentralising key assets, if viable, to reduce disruption and recovery time.

Emergency response. Recommendations include organising community debates or forums about risk to make people recognise and address their own vulnerabilities and to help them identify preventive measures that may work for them. Developing such an intrinsic community resilience would relieve the current high burden on government disaster recovery resources. Aims for educating the BA population should include activities that increase flood awareness, such as staging mock evacuation scenarios. Educational activities should also include information about how to stockpile vital consumables and how to design personalised evacuation plans.

Improving and systematising data collection and public accessibility to forecasts, risk warnings and GIS data, perhaps via mobile phone apps and social media, would probably yield good results for BA. Data need to be formatted in different ways to meet end users' needs, which include the protection of communities, properties and lives; the management of businesses affected by flooding; or the organisation of alternative supply chain routes. The means of communication from response agencies to the public should to be selected based on target audiences. Young people respond well to mobile phone apps and social media, for example. Liability should also be considered when disseminating information, as misleading information can affect property market values and safety during evacuations.

An early post-flood assessment of utilities, key infrastructure, roads, buildings and rubbish disposal requirements would facilitate the overall BA emergency response, and would go a long way to avoiding unnecessary accommodation costs. Traffic management strategies should also be considered by authorities as a tool to direct evacuees to and from evacuation centres, especially during rush hour, when there is more traffic congestion. A practical alternative to overcoming any deficiency in resources caused by acute demand during a flood emergency might include gaining access to resources from other agencies or cities. This solution might also be useful for other developing cities exposed to floods, sea-level rises, population growth and rapid land subdivision.

Model refinements and future research. The first recommendation is to increase flood model resolution by updating the 1990 baseline flood scenario to current scenario. Integrating variables should also provide improved precision to flood models. For example, surface flooding, conditions preceding and following a flood event (e.g., saturated soils due to previous precipitation), and future changes in flood risk (e.g., changes in the drainage system, or evolving coastal–estuarine morphology), could be incorporated to make BA flood models more accurate. Other hazards, in addition to the La Plata River, such as surface flooding, flood velocity, the impact of debris, groundwater rises, coastal winds, and indirect or cascading effects, can also be included in advanced simulations.

The development of a flood damage database specific to BA is recommended to calibrate depth–damage curves, which would facilitate estimations of building damage. More detailed data, including a BA building inventory at the tax-lot level, and a comprehensive survey of infrastructure lifelines and utilities, which are currently insufficient or missing, can also help to refine flood damage assessments. Creating strategic partnerships with service companies to update lifelines and utilities in a georeferenced database, and collecting information about system vulnerabilities and performance during floods, would allow an accurate and quantitative impact assessment of the city's essential lifelines. Indirect flood impacts, effects of utility interdependencies and business disruption should be addressed in future research.

Recording evacuation decisions (e.g., route, ultimate destination and means of transport) is also recommended for future flood events. The next National Census (2020) could be used for this purpose, so as to avoid the separate development of flood-specific surveys, which implies extra resources. Such a census-based survey could investigate BA population behavioural patterns, congestion hotspots, time taken to traverse flooded areas and crowd flow-rates. A survey could also encompass agent-based modelling approaches, which consider individual differences in physical fitness and impacts of carrying possessions, to improve evacuation models. In addition, flood models should be reviewed regularly with local emergency managers, and potentially, updated with live data as flood events unfold. Live data updates could include weather forecasts, traffic congestion elements, and information about obstacles interfering with traffic.

Improving the characterisation of BA's flood-exposed population with the use of other sources of information rather than Census data, which are collected every 10 years, will be necessary in the dynamic landscape that is BA. For example, using mobile apps, online or phone surveys on a more regular basis, can inform BA authorities about the people they seek to protect from floods. A better socio-economic characterisation of the population, together with a clear understanding of behavioural patterns during flood events, will ensure understanding of the relationships between demographic variables and evacuation decisions. Such improvements will also validate flood and evacuation models to the point where accurate, timely decisions can be made based on models and current data.

Reference List

ACARA (Association of car dealers of the Argentine Republic). (2017). ACARA — *Guia oficial de precios* [Official price guide]. Retrieved from http://www.acara.org.ar

Alabdouli, K. (2015). *Tsunami evacuation: Using GIS to integrate behavioral and vulnerability data with transportation modeling* (Doctoral dissertation). Retrieved from diginole.lib.fsu.edu/islandora/object/fsu:252919/datastream/PDF/view

ArcGIS. (2012). ArcGIS online directions and routing services coverage. Retrieved from https://www.arcgis.com/home/

Australian Red Cross. (2013). *Queensland evacuation centre planning toolkit*. Brisbane, Australia: Author.

Barachetti, A. (2016). *Staying afloat—Flood risk in Argentina*. Zurich, Switzerland: Swiss Re.

Barros, V., Menéndez, A., Natenzon, C., Kokot, R., Codignotto, J., Re, M., … Ríos, D. M. (2006). Vulnerability to floods in the metropolitan region of Buenos Aires under future climate change. Washington, D.C.: Assessments of Impacts and Adaptations to Climate Change.

BC Housing. (2017). *Field manual*. Burnaby, Canada: Author.

Benn, H. (2009). *Investing for the future: Flood and coastal risk management in England, a long-term investment strategy*. Bristol, UK: Environment Agency.

Bewsher Consulting Pty Ltd. (2009). *Eastwood and Terrys Creek floodplain risk management study and plan, City of Ryde*. Epping, NSW, Australia: Author.

Buckland, J., & Rahman, M. (1999). Community-based disaster management during the 1997 Red River flood in Canada. *Disasters*, *23*(2), 174–191.

Buenos Aires Ciudad. (2016). *Estadística y Censos*. Retrieved from https://www.estadisticaciudad.gob.ar/eyc/?cat=141

Buenos Aires Defensa Civil. (2016). *Plan operativo inundaciones por precipitaciones* [Operative plan for floods caused by rainfall]. Buenos Aires, Argentina: Author.

Burger, J. M., & Palmer, M. I. (1992). Changes in and generalization of unrealistic optimism following experiences with stressful events: Reactions to the 1989 California earthquake. *Journal of Personality and Social Psychology, 18*, 39–43.

Cancillería Argentina (Argentinian chancellery). (2007). National Platform for Disaster Risk Reduction. Retrieved January 30, 2018, from http://cascosblancos.gob.ar

CARP (Administrative Comission of the La Plata River). (1989). *Estudio para la evaluación de la contaminación en el Río de la Plata, SHN y SOHMA*. Buenos Aires, Argentina: Author.

Castañeda, M. E., & Barros, V. (1994). Las tendencias de la precipitación en el Cono Sur de América al este de los Andes [Precipitation tendencies in South America in th east of the Andes]. *Meteorológica, 19*(1), 23–32.

Cerca de 50 muertos en Argentina tras tormenta [Almost 50 deaths after storm in Argentina]. (2013, April 13). BBC Mundo. Retrieved from http://www.bbc.com/mundo/

Christchurch City Council. (n.d.). *Roads affected by flooding: Christchurch City Council*. Retrieved from https://www.ccc.govt.nz

Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., … Unnikrishnan, A. (2013). Sea level change. In J. Jouzel, R. van de Wal, P. L. Woodworth, & Cunde Xiao (Eds.), *Climate change 2013: The physical science basis*. Contribution of the Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1138–1216). Cambridge, U.K.: Cambridge University Press.

CIMA (Sea and Atmospheric Research Centre). (2016). Capitulo 5: Cambios climáticos en la Region Húmeda [Chapter 5: Climate change in the humid region] . *Tercera Comunicación Nacional de Cambio Climático*. Buenos Aires, Argentina: Author.

Civil Defence Emergency Management Act 2002, New Zealand Statues, S60. (2002).

Clichevsky, N., & Herzer, H. M. (2000). Floods in Buenos Aires: Learning from the past. In A. Kreimer & M. Arnold (Eds.), *Managing disaster risk in emerging economies* (pp. 32–44). Washington D.C.: World Bank Publications.

Costa, L. A. (1988). Las inundaciones en el área metropolitana de Buenos Aires [Floods in the metropolitan area of Buenos Aires]. Medio ambiente y urbanización. *Medio Ambiente Y Urbanización*, *7*(23), 2-19.

Cuesta, A., Abreu, O., & Alvear, D. (Eds.). (2015). *Evacuation Modeling Trends.* Springer.

Department of Homeland Security (U.S.). (n.d.). *Emergency response plan*. Retrieved from https://www.ready.gov/business/implementation/emergency

D'Onofrio, E. E., Fiore, M. M. E., & Ruiz, E. H. (2003). Tendencia relativa del nivel medio del Río de La Plata en el Puerto de Buenos Aires [Relative tendency of the La Plata River mean level in Buenos Aires port]. *Contribuciones a la Geodesia Aplicada*. (Vol. 1). Buenos Aires, Argentina: Instituto de Geodesia de la Facultad de Ingeniería de la Universidad de Buenos Aires.

D'Onofrio, E. E., Fiore, M. M. E., & Romero, S. I. (1994). *Tendencias del nivel medio del mar en el litoral argentino* (Informe técnico n° 76) [Mean sea level trends in the argentine coast (Technical report n°76)]. Buenos Aires, Argentina: Servicio de Hidrografia Naval.

D'Onofrio, E. E., Fiore, M. M. E., & Romero, S. I. (1999). Return periods of extreme water levels estimated for some vulnerable areas of Buenos Aires. *Continental Shelf Research*, *19*, 1681–1693.

D'Orazio, M., Quagliarini, E., Bernardini, G., & Spalazzi, L. (2014). EPES — Earthquake pedestrians' evacuation simulator: A tool for predicting earthquake pedestrians' evacuation in urban outdoor scenarios. *International Journal of Disaster Risk Reduction*, *10*, 153–177.

Deltares, Bosch Slabbers, Sweco, Witteveen+Bos, & KNMI Consortium. (n.d.). *Adaptive solutions*. Retrieved from http://www.climateapp.org/

Direccion General de Logistica (General Directorate of Logistics). (2016). Plan operativo inundacion por precipitaciones y sudestadas [Operative plan for floods caused by rainfall and southeasterly winds], Buenos Aires, Argentina: Author.

Drabek, T. E. (2000). *The social factors that constrain human responses to flood warnings*. (Vol 1). (D. Parker, Ed.). London, U.K.: Routledge.

ENEL (National Board of Electricity). (n.d.) *ENEL Generacion costanera*. Retrieved from https://www.enel.com.ar/es/enel_generacion_costanera

Escobar, G., Camilloni, I., & Barros, V. (2003, March). *Desplazamiento del anticiclón subtropical del Atlántico Sur* [The shift of the South Atlantic subtropical high]. Paper presented at X Congreso Latinoamericano e Ibérico de Meteorología [Tenth Latin American and Iberic Congress of Meteorology], La Habana, Cuba.

Escobar, G., Vargas, W., & Bischoff, S. (2004). Wind tides in the Rio de la Plata estuary: Meteorological conditions. *International Journal of Climatology, 24*(9), 1159–1169.

Fedeski, M., & Gwilliam, J. (2007). Urban sustainability in the presence of flood and geological hazards: The development of a GIS-based vulnerability and risk assessment methodology. *Landscape and Urban Planning*, *83*(1), 50–61.

Felsenstein, D., & Lichter, M. (2014). Social and economic vulnerability of coastal communities to sea-level rise and extreme flooding. *Natural hazards*, *71*(1), 463-491.

FEMA (U.S. Federal Emergency Management). (n.d.). *Multi-hazard loss estimation methodology: HAZUS-MH 2.1 user manual*. Washington, D.C.: Author.

FEMA. (2001). *Engineering principles and practices for retrofitting flood-prone residential structures*. FEMA P-259, Edition 2. Washington, D.C.: Author.

FEMA. (2008, June). *Guidelines for design of structures for vertical evacuation from tsunamis*. Washington, D.C.: Author.

FEMA. (2017). *Summary of databases in HAZUS-FEMA*. Retrieved from https://www.fema.gov/summary-databases-hazus-multi-hazard

Flood risk areas in France. (2015). Retrieved from https://www.french-property.com/news/french_property/flood_risk_areas/

Foster, S., & Garduño, H. (2002). *Argentina — Mitigation of groundwater drainage problems in the Buenos Aires conurbation: Technical and institutional way forward*. Geneva, Switzerland: World Bank.

Fraser, S. A. (2014). *Informing the development of tsunami vertical evacuation strategies in New Zealand*. (Doctoral dissertation). Retreived from https://mro.massey.ac.nz/handle/10179/6277.

Gasalla, J. (2017, April 29). La inflación anual quebró el piso del 30% y es la más baja de la era Macri [Annual inflation broke the 30% benchmark and is the lowest of the Macri era]. *Infobae*. Retreived from https://www.infobae.com/economia/2017/04/29/la-inflacion-anual-quebro-el-piso-del-30-y-es-la-mas-baja-de-la-era-macri/

GCABA. (n.d.). *Manual de diseno urbano* [Urban design manual]. Retrieved from http://www.buenosaires.gob.ar/desarrollourbano/

GCABA. (2009). *Plan director de emergencias* [Emergency management plan]. Pub. L. No. Decree 695/09 (2009). Buenos Aires, Argentina.

GCABA. (2010). *Atlas ambiental de Buenos Aires* [Buenos Aires environmental atlas] — *Saneamiento*. Retrieved from http://www.atlasdebuenosaires.gov.ar/aaba/

GCABA. (2014). *Plan Director de Ordenamiento Hidráulico* [Hydraulic master plan] . Ciudad de Buenos Aires, Argentina: Author.

GCABA (Government of the Autonomous City of Buenos Aires). (n.d.). *Estadística y censos* [Census and statistics]. Retrieved from https://www.estadisticaciudad.gob.ar

GCABA. (2015a). *Plan de acción frente al cambio climático* [Action plan in the face of climate change]. Retrieved from http://cdn2.buenosaires.gob.ar/espaciopublico/apra/pacc_2020.pdf

GCABA. (2015b). *Plan estratégico Buenos Aires 2030* [Buenos Aires strategic plan 2030]. Retrieved from http://www.buenosaires.gob.ar/sites/gcaba/

GFZ (Geo Research Center). (2015). *HOWAS 21 — the web-based information system on flood damage in Germany*. Retrieved from http://howas21.gfz-potsdam.de

Golder Associates, & Deltares. (2017). *Protection options for managing groundwater in South Dunedin*. Dunedin, New Zealand: Authors.

González, S. (2005). Ciudad visible versus ciudad invisible: La gestión por riesgo por inundaciones en la ciudad de Buenos Aires [Visible city versus invisible city: flood risk managment in the city of Buenos Aires]. *Territorios* (*Agosto-Enero*), 53–67.

Haasnoot, M., Kwakkel, J. H., Walker, W. E., & ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, *23*(2), 485–498.

Handmer, J. (2000). Are flood warnings futile? Risk communication in emergencies. *The Australasian Journal of Disaster and Trauma Studies*, *2, 2000-2*.

Harrower, M., & Brewer, C. A. (2003). The cartographic journal ColorBrewer.org: An online tool for selecting colour schemes for maps. *The Cartographic Journal*, *40*(1), 27–37.

Houston, J. B., Hawthorne, J., Perreault, M. F., Park, E. H., Goldstein Hode, M., Halliwell, M. R., … Griffith, S. A. (2015). Social media and disasters: A functional framework for social media use in disaster planning, response, and research. *Disasters*, *39*(1), 1–22.

INDEC (Argentina's National Institute of Statistics and Census). (2010). *Web Instituto Nacional de Estadistica y Censo — Población / Censos / Censo 2010*. Retrieved April 6, 2016, from http://www.indec.gov.ar

INDEC. (2012). *Encuesta Nacional sobre Calidad de Vida de Adultos — Mayores 2012: ENCaViAM* [National survey of the quality of life of elederly people 2012: ENCaViAM]. Retrieved from https://www.indec.gov.ar/ftp/cuadros/sociedad/encaviam.pdf

IPCC (Intergovernmental Panel on Climate Change). (2001a). *Cambio climático 2001: Impactos, adaptación y vulnerabilidad* [Climate Change 2001: Impacts, adaptation and vulnerability]. Contribución del Grupo de trabajo II al Tercer informe de evaluación del IPCC. Cambridge, U.K.: Cambridge University Press.

IPCC. (2001b). *Cambio climático 2001: La base científica*. Contribución del Grupo de trabajo I al Tercer informe de evaluación del IPCC [Climate change 2001: the scientific basis. Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change]. Cambridge, U.K.: Cambridge University Press.

IPCC. (2013). *Climate change 2013: The physical science basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, U.K.: Cambridge University Press.

Karamouz, M., Fereshtehpour, M., Ahmadvand, F., & Zahmatkesh, Z. (2016). Coastal flood damage estimator: An alternative to FEMA’s HAZUS platform. *Journal of Irrigation and Drainage Engineering*, *142*(6), 1–12.

Karamouz, M., Zahmatkesh, Z., Goharian, E., & Nazif, S. (2014). Combined impact of inland and coastal floods: Mapping knowledge base for development of planning strategies. *Journal of Water Resources Planning and Management*, *141*(8), 04014098.

Kim, N. (2012). How much more exposed are the poor to natural disasters? Global and regional measurement. *Disasters*, *36*(2), 195–211.

Knook, P., Hansen, R., Shand, T., Russ, N., Reinen-Hamill, R., & Baunton, P. (2015). Tsunami evacuation modelling and mitigation measures for Tauranga City , New Zealand. *Coast and Ports 2015* (September), 1–9.

Koks, E. E., Jongman, B., Husby, T. G., & Botzen, W. J. W. (2015). Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. *Environmental Science and Policy*, *47*, 42–52.

Koutsovitis, M., & Goyeneche, M. (n.d.). *Inundaciones en cuencas urbanas* [Floods in urban catchments]. Retrieved from http://campus.fi.uba.ar/

Las imágenes de las inundaciones [The images of the flood]. (2013, April 2). *Ambito*. Retrieved from http://www.ambito.com/682145-las-imagenes-de-las-inundaciones

Lanfredi, N. W., Pousa, J. L., & D'Onofrio, E. E. (1998). Sea-level rise and related potential hazards on the Argentine coast. *Journal of Coastal Research*, 47-60.

La tormenta de abril: la más terrible de la historia [The april storm: the most terrible in the history]. (2013, April 3). *Clarin*. Retrieved from https://www.clarin.com/ciudades/tormenta-abril-terrible-historia_0_ryLQDYYjvXx.html

Layfield, F. (1987). *Sizewell B public inquiry*. London, U.K.: HMSO.

Le, L. (2016). *Tsunami evacuation model for Sumner, Christchurch, New Zealand* (Master´s thesis, University of Canterbury, Christchurch, New Zealand). Retrieved from https://ir.canterbury.ac.nz/handle/10092/12764

Lecertua, E. A. (2010). *Análisis de riesgo de duración de inundaciones en las áreas costeras del Río de la Plata considerando Cambio Climático* [Risk analysis of flood duration on the coast of the La Plata River considering climate change] (Undergraduate thesis, Universidad de Buenos Aires, Buenos Aires, Argentina). Retrieved from https://www.ina.gov.ar/legacy/

Lindell, M. K., & Prater, C. S. (2007). Critical behavioral assumptions in evacuation time estimate analysis for private vehicles: Examples from hurricane research and planning. *Journal of Urban Planning and Development*, *133(*1), 18–29.

Mapzen. (n.d.). *Metro extract Buenos Aires*. Retrieved August 1, 2017, from https://mapzen.com/data/

MAyDS (The Ministry of Environment and Sustainable Development). (n.d.). Sistemas de Mapas de Riesgo del Cambio Climático [Climate change risk maps system]. Retrieved December 5, 2017, from http://simarcc.ambiente.gob.ar/

MBIE. (2014). *Building assessment field guides and forms*. Retrieved from https://www.building.govt.nz/managing-buildings/post-emergency-building-assessment/field-guides-and-tools-for-building-assessment/

MDUyT (Ministry of Urban Development and Transportation). (2017a). *Código urbanístico — Version 10* [Urban code version 10]. Buenos Aires, Argentina: Author.

MDUyT. (2017b). *Nuevo código de edificación — En proceso de redacción* [New building code — in progress] . Buenos Aires, Argentina: Author.

Medina, N., Sanchez, A., & Vojinovic, Z. (2016). The potential of agent based models for testing city evacuation strategies under a flood event. *Procedia Engineering*, *154*, 765–772.

Merz, B., Kreibich, H., Schwarze, R., & Thieken, A. (2010). Assessment of economic flood damage. *Natural Hazards and Earth System Sciences*, *10*, 1697–1724.

Messner, F., Penning-Rowsell, E., Green, C., Meyer, V., Tunstall, S., & Van Der, A. (2006). *Guidelines for socio-economic flood damage evaluation*. Report T9-06-01. Wallingford, UK: Floodsite Consortium.

MPyOP (Ministry of Planning and Public Works). (2006). *Plan urbano ambiental* [Urban and environmental plan]. Retrieved from http://www.buenosaires.gob.ar/areas/planeamiento_obras/copua/

Ministerio de Trabajo, Empleo y Seguridad Social (Ministry of labor, employment and social security). (2016). Servicios e información [Services and information]. Retrieved from http://www.trabajo.gob.ar/domestico/normativa.asp?id_seccion=145

Ministerio de Transporte (Ministry of Transport). (2009). *2009-2010 Movilidad en el area metropolitana de Buenos Aires* [Mobility in the metropolitan area of Buenos Aires]. Retrieved October 6, 2017, from http://uecmovilidad.gob.ar

Mohammadi, S. A., Nazariha, M., & Mehrdadi, N. (2014). Flood damage estimate (quantity), using HEC-FDA model. Case study: the Neka River. *Procedia Engineering*, *70*, 1173-1182.

Nastev, M., & Todorov, N. (2013). A standardized methodology for flood risk assessment in Canada. *Canadian Water Resources Journal*, *38*(3), 223–231.

Natenzon, C. E., González, S., Gentile, E., Rios, D., & Boudin, C. (2003). *Social vulnerability, climatic change and floods*. Presented at the Assessments of Impacts and Adaptations to Climate Change (AIACC), Latin America/Caribbean Regional Workshop. San José, Costa Rica: AIACC.

New Zealand Civil Defence. (n.d.). *Personal workplace emergency plan*. Retrieved October 17, 2017, from http://getthru.govt.nz/assets/Uploads/personal-workplace-emergency-plan.pdf

New Zealand Civil Defence. (2008). *Mass evacuation planning*. Wellington, New Zealand: Author.

Novick, A., Collado, F., & Favelukes, G. (n.d.). *Atlas ambiental de Buenos Aires — Urbanización* [Buenos Aires environmental atlas — Urbanisation]. Retrieved November 4, 2016, from http://www.atlasdebuenosaires.gov.ar

Page, J., & Adams, J. (2003). International migration, remittances, and poverty in developing countries. *World Bank Policy Research Working Paper 3179*. Washington D.C.: World Bank.

Paton, D., Smith, L., Daly, M., & Johnston, D. (2008). Risk perception and volcanic hazard mitigation: Individual and social perspectives. *Journal of Volcanology and Geothermal Research*, *172*(3–4), 179–188.

Penning-Rowsell, E. C., & Green, C. (2000). New Insights into the appraisal of flood-alleviation benefits: (1) Flood damage and flood loss information. *Water and Environment Journal, 14*(5), 347–353.

Penning-Rowsell, E., Johnson, C., Tunstall, S., Tapsell, S., Morris, J., Chatterton, J., … Fernandez-Bilbao, A. (2005). *The benefits of flood and coastal risk management: A handbook of assessment techniques*. Middlesex, U.K.: Middlesex University Press

Penning-Rowsell, E., & Pardoe, J. (2012). Who loses if flood risk is reduced: Should we be concerned? *Area*, *44*(2), 152–159.

Penning-Rowsell, E., Priest, S., Parker, D., Morris, J., Tunstall, S., Viavattene, C., … Owen, D. (2013). *Flood and coastal erosion risk management: A manual for economic appraisal*. Abingdon, U.K.: Routledge.

Penning-Rowsell, E., & Wilson, T. (2006). Gauging the impact of natural hazards: The pattern and cost of emergency response during flood events. *Transactions of the Institute of British Geographers, 31*, 99–115.

Pets Evacuation and Transportation Standards Act, United States Statutes. (2006).

Pfurtscheller, C., & Schwarze, R. (2008). Estimating the costs of emergency services during flood events. In *Proceedings of the 4th International Symposium on Flood Defence*, Toronto (pp. 1–8). Ontario, Canada: .

Rakow, T., Heard, C. L., & Newell, B. R. (2015). Meeting three challenges in risk communication: Phenomena, numbers, and emotions. *Behavioral and Brain Sciences*, *2*(1), 147–156.

Re, M., & Menéndez, A. (2005). *Impacto del cambio climático global en las Costas del Río de la Plata* [Global climate change impacts on the coast of the La Plata River] (Master´s thesis thesis, Universidad de Buenos Aires, Buenos Aires, Argentina). Retrieved from https://www.ina.gob.ar/index.php?seccion=21

Reeder, T., & Ranger, N. (2011). *How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project*. Washington D.C.: World Resources Report.

Reese, S., & Ramsay, D. (2010). *RiskScape: Flood fragility methodology*. Report WLG2010-45. Wellington, New Zealand: National Institute of Water & Atmospheric Research (NIWA).

Remo, J. W. F., Pinter, N., & Mahgoub, M. (2016). Assessing Illinois's flood vulnerability using Hazus-MH. *Natural Hazards, 81*, 265–287.

Revi, A., Satterthwaite, E., Aragón, F., Balbus, J., Cardona, O.D., Barros, R., … MacCracken, S. (2014). Urban areas. In J. Balbus & O.D Cardona (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability*. *Part A: Global and sectoral aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 535–612). Cambridge, U.K.: Cambridge University Press.

Riggs, M. A., Rao, C. Y., Brown, C. M., Sickle, D.V., Cummings, K. J., Dunn, K. H., … Pinkerton, L. E. (2008). Resident clean-up activities, characteristics of flood-damaged homes and airborne microbial concentrations in New Orleans, Louisiana, October 2005. *Environmental Research*, *106*, 401–409.

Robos y saqueos después de la tormenta en el Gran Buenos Aires [Robbery and looting after the storm in Great Buenos Aires]. (2013). Retrieved October 27, 2017, from http://necocheahoy.com

Saunders, W. (2010). How long is your piece of string — Are current planning timeframes for natural hazards long enough? Christchurch, New Zealand: New Zealand Planning Institute.

Scawthorn, C., Asce, F., Flores, P., Blais, N., Seligson, H., Tate, E., … Lawrence, M. (2006). HAZUS-MH flood loss estimation methodology. II. Damage and loss assessment. *Natural Hazards Review*, *7*(2), 72–81.

Secretaría de Transporte (Transport Secretariat). (2007). *Investigación de transporte urbano de Buenos Aires* [Research on urban transport in Buenos Aires]. Retrieved from http://datar.info//dataset/

Sejenovich, H., & Cock Mendoza, G. (2000). Economic Aspects of Floods: The Case of Argentina. In A. Kreimer & M. Arnold (Eds.), *Managing disaster risk in emerging economies* (pp. 22–31). Washington DC, USA: World Bank Publications.

Shabman, L., Stephenson, K., Thunberg, E., Dietz, B., Driscoll, P., & O'Grady, K. (1998). *Comparing benefit estimation techniques: Residential flood hazard reduction benefits in Roanoke, Virginia* (No. IWR-98-R-2). Alexandria, V.A.: U.S. Army Corps of Engineers Institute for Water Resources.

Sjoberg, L. (2000). Factors in risk perception. *Risk Analysis*, *20*(1), 1–12.

Smith, K., & Ward, R. (1998). *Floods : Physical processes and human impacts*. Hoboken, N.J.: John Wiley & Sons.

Standards New Zealand. (2009). *AS/NZS ISO 31000:2009 risk management*. Wellington, New Zealand: MBIE.

Stephens, S. (2015). *The effect of sea-level rise on the frequency of extreme sea levels in New Zealand*. Hamilton, New Zealand: NIWA.

Sterr, H., Markau, H. J., Reese, S., Kiel, C., Markau, H. J., & Reese, S. (2005). *Analysis of previous vulnerability studies in the pilot site German Bright Coast*. Wallingford, U.K.: Floodsite Consortium.

Stone, E. R., Yates, J. F., & Parker, A. M. (1994). Risk communication: Absolute versus relative expressions of low-probability risks. *Organizational Behavior and Human Decision Processes*, *60*(3), 387–408.

Tan, M. L., Prasanna, R., Hudson-Doyle, E., Stock, K., Leonard, G., & Johnston, D. M. (2016). *A review: Crisis informatics and mobile applications in building resilience*. Paper presented at the 6th International Conference on Building Resilience (pp. 504–516). Auckland, New Zealand.

Temporal en Ciudad y GBA dejó dos muertos y evacuados [Storm in the city and GBA left two deaths and evacuees]. (2012, October 29). *Ambito*. Buenos Aires. Retrieved from http://www.ambito.com/660650-temporal-en-ciudad-y-gba-dejo-dos-muertos-y-evacuados

TomTom Traffic Index. (2016). *Buenos Aires traffic congestion statistics*. Retrieved August 25, 2017, from https://www.tomtom.com

UN (United Nations). (2009). *Economics of climate change in Latin America and the Caribbean*. Summary 2009. Santiago, Chile: Author.

UN-SPIDER (United Nations Platform for Space-based Information for Disaster Management and Emergency Response). (n.d.). *Disaster risk management | UN-SPIDER knowledge portal*. Retrieved November 23, 2017, from http://www.un-spider.org/risks-and-disasters/disaster-risk-management

UNISDR (United Nations International Strategy for Disaster Reduction). (n.d.). *DesInventar — Profile*. Retrieved October 2, 2017, from http://www.desinventar.net/DesInventar/profiletab.jsp

UNISDR. (2015). *Sendai framework for disaster risk reduction 2015-2030*. Geneva, Switzerland: Author.

UNISDR. (2017). Sendai Framework Data Readiness Review — Argentina. Retrieved from https://www.preventionweb.net/files/54272_argentinaarg.pdf

UNLP (National University of La Plata). (2013). *Estudio sobre la inundación ocurrida los días 2 y 3 de abril de 2013 en las ciudades de La Plata, Berisso y Ensenada* [Study on the flood occurred on April 2nd and 3th in the city of La Plata, Berisso and Ensenada]. La Plata, Argentina: Author.

USACE (United States Army Corps of Engineers). (2003). *Economic guidance memorandum (EGM) 04-01, generic depth–damage relationships for residential structures with basements*. Washington DC.: Author.

Vecinos del barrio Mitre y el Dot Baires intentan solucionar el problema del desagüe [Neighbors of Mitre neighborhood and Dot Baires try to solve the drainage problems]. (2012, December 7). *La Nacion*. Buenos Aires.

Wood, N., Jones, J., Schmidtlein, M., Schelling, J., & Frazier, T. (2016). Pedestrian flow-path modeling to support tsunami evacuation and disaster relief planning in the U.S. Pacific Northwest. *International Journal of Disaster Risk Reduction*, *18*, 41–55.

World Bank. (2005). Argentina — Urban flood prevention and drainage: Environmental Impact Assessment. Report n° 31641. Buenos Aires, Argentina.

World Bank. (2016). Flood risk management support project for the autonomous City of Buenos Aires. Buenos Aires, Argentina: Author.

Wright, M. (2017, August 30). *Houston businessman turns furniture stores into shelters for Hurricane Harvey victims*. Retrieved from http://www.telegraph.co.uk/news/2017/08/30/houston-businessman-turns-furniture-stores-shelters-hurricane/

Yang, J., Townsend, R. D., & Daneshfar, B. (2006). Applying the HEC-RAS model and GIS techniques in river network floodplain delineation. *Canadian Journal of Civil Engineering*, *33*(1), 19-28.

Yin, W., Murray-Tuite, P., Ukkusuri, S. V., & Gladwin, H. (2014). An agent-based modeling system for travel demand simulation for hurricane evacuation. *Transportation Research Part C*, *42*, 44–59.

Appendices

Appendix A: Flood Mitigation

Strategies that have already been implemented in different countries and can be useful in BA to reduce (coastal, fluvial, pluvial, groundwater) flood risk, improve emergency response and resilience are presented in Table 18. However, site-specific flood risks and management approach analysis are necessary to determine the suitability of these measures in the BA context (Jeroen et al., 2014). The implementation of mitigation measures can be done progressively, starting with sensitive areas and critical infrastructure and utilities. Issues like ownership of land, financial means, responsibilities for operation and maintenance need to be addressed together with the project design.

Table 18

Strategies for Flood Mitigation and a Better Emergency Response in BA (Deltares, Bosch Slabbers, Sweco, Witteeveen+Bos, & KNMI, n.d.).

Adaptation solution	Description	Advantages	Disadvantages
Sealable buildings (dry proof)	More robust materials such as concrete, steel and glass can be used to make the interior of buildings or infrastructures waterproof. Also, basements can be elevated, and power-supply boxes can be moved upstairs. In addition, the exterior of buildings can be made waterproof, and gaps and holes	Reduction of damages, repair costs and recovery time.	It might be more difficult to implement in existing buildings. Incentives for homeowners to implement this measure might be needed.

	should be sealed below design water level. This is possible if design water levels do not exceed ground floor level. (e.g. Vietnam, Germany)		
Amphibious (floatable) buildings	Amphibious buildings are located on land, and only float during a flood period. Like floating buildings, they are fixed to posts in a horizontal direction to avoid drift of the building. (e.g. in the Netherlands)	The increase of usable surface and reduce the loss of land for development.	The lifting of the float can be difficult after some years of stationary position on the ground floor during a rapid rise in water levels. Infrastructure connections need to flexible to be able to resist water level variations.
Raised curbs, hollow roads or sunken channels	Raised curbs and hollowed roads allow increasing the storage and transport capacity of a road instead of water flowing into buildings directly.	Access to buildings is protected and damage reduced.	Handicapped access is more complex.
Temporary flood protection (e.g. sand bags, inflatable construction, stoplogs)	Temporary perimeter flood barriers consist of complete removable components, which are installed following a flood warning and dismounted after the end of a flood period. (e.g. in Scotland, and Germany)	It takes less space and it does not affect accessibility like permanent flood protection.	A storage location and training is needed to build a flood protection in time.

Check valve-non-return valves	They avoid backflow in flood conditions for example in toilets and sewer systems.	Prevents flood water entering the building. Damage reduction.	Incentives might be needed for homeowners.
Infiltration and Transport-sewer	The infiltration and transport-sewer (IT) sewer is a permeable pipeline that allows water to infiltrate into the soil. When soils are fully saturated and water can no longer infiltrate, the IT sewer works as a storm water drain and excess water is transported along the pipe and discharged into another water body.	The IT sewer is able to reduce flooding and improve water availability during dry periods.	It is easier to implement in new buildings or developments.
Improve soil infiltration capacity (porous pavement, permeable surfaces for walks and driveways groundcover, shrubbery)	Trees, shrubs, and porous pavements facilitate the infiltration of water, reduce its velocity and reduce runoff. Multilevel parking, and high rise instead of low-level buildings can contribute to decreasing paved impermeable surface areas.	Planted surfaces reduce runoff and also cool the environment through evapotranspiration and by providing shade, reducing the heat island effect, improving air quality, water quality and the livability of a city. Porous pavements trap suspended solids and filter pollutants in the soil, thus improving water quality.	It is necessary to promote permeable surfaces in the building code.

Seasonal storage (small lakes within the city, on roofs, in water squares, water tanks, or rainwater storage below buildings)	Water can be stored during rainy seasons on roofs, in a water tank alongside the house or underneath buildings, water squares or in small lakes within the city and groundwater recharge zones. The stored water can later be used during dry seasons reducing the demand on the system.	It reduces runoff and water shortages in dry periods. The stored water can be used for non-potable purposes or drinking after treatment.	Space availability. Incentive and training might be necessary to encourage people to install water tanks and to install them appropriately. If the stored water is for drinking purposes, additional filtration and treatment devices, are necessary.
Airbag water storage	An underwater bag is fastened to a structure to prevent floatation. During heavy rainfall, the airbag is emptied to reduce water level rise. Later, when storage space is no longer needed the airbag can be re-inflated.	The airbags maintain a static water level during rainfall and provide increased water storage within a confined area.	Space availability. Incentive and training might be necessary to encourage people to install the airbags.
Water squares and water basins	The square can be used as a recreational space on dry days or as a water storage space during rainfall events. Rainwater collected from the surrounding area will flow into the square and slowly discharged to the water system.	They not only provide water storage capacity but also aesthetic and recreational value to the urban environment.	Space availability.

	Water basins are retention ponds constructed to store water during floods or for dry periods.		
Relocation of critical buildings, utilities, facilities and infrastructure	Relocation of public utilities, buildings that store dangerous goods and vital infrastructure to higher ground is an alternative to minimise flood risk and guarantee their functionality during flood events. When relocation is not feasible, permanent or dismountable elevated quays, gates or flood walls can be a more practical alternative.	Flood risk reduction. Facilities´ functionality is guaranteed.	Cost-benefit analyses are necessary to evaluate if relocation is more beneficial than paying for infrastructure and utilities´ flood damages. Budget or space availability can be a burden.
Deep groundwater infiltration	Rainwater is collected and infiltrated in deep wells to recharge deep aquifers.	No need to use the limited urban surface area.	Hydrogeological assessments are necessary to avoid the rise of the water table which is already shallow in some areas of BA or contamination of aquifers.
Building on partially elevated areas	A building in a floodplain can be constructed on an elevated area while the surrounding area is allowed to be flooded.	Damage reduction.	Flood risk is only reduced locally so access to the building might be limited. More practical for new

			buildings and developments.
Water portal	Surface/groundwater issues, their causes, monitoring results and projects are communicated through the “Water portal” in a non-technical way for the general public. It can be financed from sewage tax (e.g. Hoogeveen-The Netherlands).	It can help to create buy-in from the community and raise awareness. Timely, transparent and targeted information for stakeholders allows them to implement suitable flood mitigation measures on their properties.	The information needs to be updated frequently and formatted to achieve users´ needs. Liability should be considered when disseminating information.
Managed retreat	Site clearing and limitation of the hazard area to a non-urban function to allow the area to become flooded. Building consents are no longer issued and services are not maintained. (e.g. Christchurch-New Zealand, Odense-Denmark)	Damage reduction.	Significant costs for loss of property. High impact on communities. Relocation might be difficult in a densely populated urban environment.
Emergency response			
Evacuation routes at an elevated level	Evacuation routes at an elevated level can provide a safe route in flood events to reach safe areas. They should be constructed above the highest predicted flood level (e.g. Germany).	Safe evacuation.	Need to be designed together with existing or projected shelters and safe areas. The capacity of the elevated route can be a burden.

Emergency exit of buildings above highest flood level	Emergency exits should be constructed at the highest flood level to avoid the blockage of exits by flood water or debris. They can be located on rooftops or existing windows, which can be redesigned as emergency exits.	Safe evacuation.	More practical for new buildings. Incentives might be necessary for property owners.

Appendix B: Questionnaire for Local Authorities & Civil Defence and Human Ethics Approval

1. Which are the main natural hazards that the Local Council/Civil Defence consider most likely to affect Buenos Aires city?

2. Is climate change and/or sea level rise being considered for flood mitigation measures?

3. Is there a specific emergency plan for flood events?

4. Which factors are contemplated for emergency planning? What are the data sources? (E.g. Flood models, Historic flood events/Census/ Meteorological/Hydrological information…)

5. Are the following aspects considered in the emergency plan: Rubbish collection, business disruption, cleanup costs, evacuation pathways housing and welfare of evacuees?

6. Are flood models and/or Risk management software being used for emergency planning?

7. Who are the authorities/institutions in charge of providing an emergency response? Are they professionals or have relevant experience in Hazards management? How is emergency planning funded?

8. Are there any collaboration agreements between local authorities/Civil Defence, and NGOs/Universities/Communities?

9. Based on your professional experience, do you consider that flood emergency response is adequate for Buenos Aires? What are the strengths and limitations of Buenos Aires emergency plan? Any recommendations?

10. Are there specific plans for protecting/repairing electricity sub-stations? Emergency generators for critical facilities such as hospitals and health clinics? Potable water and waste water pump stations? Contamination of water supplies? Environmental contamination by petrol stations? Preparedness for damage to bridges and roads?

HUMAN ETHICS COMMITTEE

Secretary, Rebecca Robinson
Telephone: +64 03 364 2987, Extn 45588
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2016/61/LR

13 October 2016

Yanina Ferligoj
Waterways Centre For Freshwater Management
UNIVERSITY OF CANTERBURY

Dear Yanina

Thank you for submitting your low risk application to the Human Ethics Committee for the research proposal titled "Assessment of Community and Infrastructure Lifeline Resilience to Floods in Buenos Aires, Argentina".

I am pleased to advise that the application has been reviewed and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 3rd October 2016.

With best wishes for your project.

Yours sincerely

pp. R. Robinson

Kelly Dombroski
Deputy Chair, Human Ethics Committee

Appendix C: Flooding Rapid Assessment From and Placards (Ministry of Business, 1985)

FLOODING RAPID ASSESSMENT FORM

Simple Residential Buildings

ASSESSMENT

Fields with asterisks (*) are mandatory, others are optional.

1. Assessor Name*
   Assessor ID* Authority*

2. Assessment Date* Day Month Year Assessment Time* Hour Minute (to nearest half hour) A AM B PM

BUILDING IDENTIFICATION

3. Unit / Number* /
   Street*
   City/Town*
   GPS (Degree with 5 decimals after comma) South – , East ,
   Other ID or access Photo taken A No B Yes Photo ID.

4. Contact Name
   Type A Owner B Tenant C Other
   Phone (with area code) (0)

5. Existing Placard* None W Y1 Y2 R1 R2 Date* Day Month Year Team ID*

BUILDING DESCRIPTION

6.

Dimensions	Constr. Age	Structure Type	Cladding Type	Lining Type
Storeys above ground incl. ground floor	A <1935	A Timber frame	A Brick veneer	A Plasterboard
	B 1935-1976	B Steel frame	B Concrete panels	B Lathe and plaster
Storeys below ground	C 1977-1984	C Reinforced masonry	C Sheet material	C Hardboard
	D 1985-2000	D Unreinforced masonry	D Weatherboard	D Softboard
	E >2000	E Other:	E EIFS	E Other:
Footprint (m²)	F Unknown		F Other:	

EXTERNAL RISKS

7.

Potential Cause*	A Yes	B No
2 Land instability above		
3 Land instability below		
4 Other		

If required add sketch on separate page showing extent and nature of the external risk factors.

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DAMAGE ASSESSMENT

8 Water height inside building above the floor* [ ][ ].[ ] m   Silt depth* [ ][ ].[ ] m

	Damage						Damage				
	N/A	Unknown	Minor or None	Moderate	Severe		N/A	Unknown	Minor or None	Moderate	Severe
Structural Damage*	N/A	A	B	C	D	Plumbing and Drainage*	N/A	A	B	C	D
1 Piles and foundations	◯	◯	◯	◯	◯	12 Gully traps	◯	◯	◯	◯	◯
2 Baseboards	◯	◯	◯	◯	◯	13 Sewerage/septic tank	◯	◯	◯	◯	◯
3 Internal bracing	◯	◯	◯	◯	◯	14 Plumbing	◯	◯	◯	◯	◯
4 Disturbed or slumped ground to compromise foundations	◯	◯	◯	◯	◯	15 Other:	◯	◯	◯	◯	◯
5 Other:	◯	◯	◯	◯	◯	Other	N/A	A	B	C	D
Water Supply*	N/A	A	B	C	D	16 Electrical systems	◯	◯	◯	◯	◯
6 Public supply	◯	◯	◯	◯	◯	17 Reticulated gas	◯	◯	◯	◯	◯
7 Roof collection	◯	◯	◯	◯	◯	18 Gas cylinders	◯	◯	◯	◯	◯
8 Bore	◯	◯	◯	◯	◯	Outbuildings*	N/A	A	B	C	D
9 Other:	◯	◯	◯	◯	◯	19 Detail:	◯	◯	◯	◯	◯
10 Tank storage ABOVE ground	◯	◯	◯	◯	◯	Comments:					
11 Tank storage BELOW ground	◯	◯	◯	◯	◯						

9 Estimated Damage   A ◯ None   B ◯ 0-10%   C ◯ 11-30%   D ◯ 31-60%   E ◯ 61-100%

SUGGESTED FURTHER ACTIONS

10

Recommended further Assessment*
- A ◯ None
- B ◯ Further evaluation to be arranged by building owner:

Urgency of suggested action*
- A ◯ Standard
- B ◯ Immediate action required

Safety Cordon*
- A ◯ None required
- B ◯ Cordon required

Describe extent (add diagram on separate sheet if required)

Barricades*
- A ◯ None required
- B ◯ Barricades already in place
- C ◯ Barricades required

Describe extent (add diagram on separate sheet if required)

SUMMARY

11

Observed Damage	Flooding Rapid Assessment Outcome*
Light or no damage	W ◯ **CAN BE USED** (From assessment no known dangers)
Moderate damage	Y1 ◯ **RESTRICTED ACCESS TO PART(S) OF THE BUILDING ONLY**
	Y2 ◯ **RESTRICTED ACCESS – SHORT TERM ENTRY ONLY** Access to be supervised A ◯ Yes B ◯ No
Heavy damage	R1 ◯ **ENTRY PROHIBITED (At risk from external factors)**
	R2 ◯ **ENTRY PROHIBITED (Severe damage to building)**

12

Survey Extent*	
Exterior	A ◯ Partial
	B ◯ Complete
Interior	C ◯ Not accessed
	D ◯ Partial
	E ◯ Complete

Assessor Signature*

NOTES

13

If required add a sketch on a separate sheet of paper showing building damage, access restrictions or cordoning areas. Identify the building on the sketch and staple the sheet to this assessment form.

Sketch included on separate page? ◯ Yes ◯ No

ENTRY PROHIBITED

(THIS IS NOT A DEMOLITION ORDER)

There has been a quick visual inspection of this building:

- ❑ This building is at risk from an external hazard
- ❑ This building has been seriously damaged

Description of hazard observed: ____________________________
____
____
____

Extent of barricades required: ____________________________
____
____
____

❑ Diagram attached showing restricted areas

Access is not permitted without written authorisation from the Civil Defence Emergency Management Controller.

Building Name and Address: ____________________________
____
____

This building has been subject to a rapid assessment:

- ❑ Exterior Only
- ❑ Exterior and Interior

Assessor ID: ____________________________

Date: ____________________ Time: ______________

This placard has been placed on behalf of the Civil Defence Emergency Management Controller under the authority of the Civil Defence Emergency Management Act 2002.

For further information:

- www.building.govt.nz/managing-buildings/post-emergency-building-assessment
- For enquires about this building: ____________________

DO NOT REMOVE THIS NOTICE

RESTRICTED ACCESS

❑ TO PART(S) OF THE BUILDING ONLY

❑ SHORT TERM ENTRY ONLY

❑ Access to be supervised by a person authorised by the issuing Territorial Authority

There has been a quick visual inspection of this building:

- This building has been damaged and its structural safety is questionable
- Enter only at own risk
- Future events may cause more damage that may change this assessment

Description of hazard observed: ____________________________
____

Restricted areas are: ____________________________
____

Restrictions on use:

- ❑ Removal of essential documents/valuables only
- ❑ Removal of property
- ❑ Other: ____________________________
____

❑ Diagram attached showing restricted areas

Building Name and Address: ____________________________
____
____

This building has been subject to a rapid assessment:

- ❑ Exterior Only
- ❑ Exterior and Interior

Assessor ID: ____________________________

Date: ____________________ Time: ______________

This placard has been placed on behalf of the Civil Defence Emergency Management Controller under the authority of the Civil Defence Emergency Management Act 2002.

For further information:

- www.building.govt.nz/managing-buildings/post-emergency-building-assessment
- For enquires about this building: ____________________

DO NOT REMOVE THIS NOTICE

CAN BE USED

NO RESTRICTIONS ON ACCESS

There has been a quick visual inspection of this building:

- No obvious structural problems were observed, but;
- This does not mean that the building is completely safe
- This does not mean that the building is not damaged
- Aftershocks may cause more damage that may change this assessment

The following items have generally not been inspected:

- Utilities (electrical, gas, water, sanitary facilities, etc)
- Secondary elements (ceilings, windows, fittings, etc)

Building owners and tenants have an important role in regard to the future safety of occupants and the public:

- The owner should organise for someone to look at the building more thoroughly
- Tell the authority if you find anything that could be dangerous

Building Name and Address: ______________________________
____
____

This building has been subject to a rapid assessment:

- ☐ Exterior Only
- ☐ Exterior and Interior

Assessor ID: ______________________________________

Date: ________________________Time: _______________

This placard has been placed on behalf of the Civil Defence Emergency Management Controller under the authority of the Civil Defence Emergency Management Act 2002.

For further information:

- www.building.govt.nz/managing-buildings/post-emergency-building-assessment
- For enquires about this building: __________________

DO NOT REMOVE THIS NOTICE